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FHWA/IN/JHRP-82/23

ENERGY CONSERVATION AND COST SAVING RELATED TO HIGHWAY ROUTINE MAINTENANCE: DATA COLLECTION AND ANALYSIS OF FUEL CONSUMPTION

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Interim Report

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TO: Harold L. Michael, Director
Joint Highway Research Project

December 15, 1982

Project: C-36-67L

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

File: 9-11-12

Attached is the Interim Report on the HPR Part II Study entitled "Energy Conservation and Cost Saving Related to Highway Routine Maintenance". The research has been conducted by Mr. Essam Sharaf, Graduate Instructor in Research of our staff under the direction of Professor K. C. Sinha, Research Engineer.

The report here is concerned with the data collection and analysis of equipment fuel consumption rates for various routine maintenance activities.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

Respectfully submitted,

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and the

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INTRODUCTION

Current highway maintenance programming process is greatly influenced by three factors: (i) increasing rate of pavement deterioration since a large part of the existing system is rapidly aging; (ii) continuing inflation and cost increase of all highway resources; and (iii) uncertainty surrounding the level of available highway revenue for routine maintenance.

The overall impact of aging of the highway system can be best illustrated by the fact that in 1975 only 4 percent of the nationwide interstate system needed resurfacing, restoring, or rehabilitation, whereas about 10 percent of the interstate system needed these activities in 1978 (1).

At the same time the inflationary and price increasing pressures in recent years made it difficult to undertake such expensive major projects as resurfacing or rehabilitation. The trend in highway programming has therefore been toward less expensive options. With the passing of the 1982 Surface Transportation Act providing additional 5 cents motor fuel tax, a substantial increase in Federal aid is expected and therefore many of the so far deferred major maintenance activities can now be considered. However, routine maintenance activities do not receive any Federal aid and they must be accomplished through the state generated revenues. Increased Federal aid also requires increased matching funds from the state sources, and thus if there are no additional state revenues, less funds for routine

maintenance may be available. Consequently, routine maintenance is receiving a considerable attention from highway agencies at all levels of government.

Resources required for routine maintenance can be grouped in terms of materials, labor, and equipment. An accurate and reliable data base of resource needs for various routine maintenance activities is a critical factor for a successful management of a maintenance program. Only with a sound information system can the alternatives and options for efficient utilization of available resources be properly evaluated.

In recent years there has been a sharp increase in cost for all petroleum related materials, such as fuel oil, asphalts, tars, and so on. In particular, the price of motor fuel has risen drastically . As motor fuel oil is one of the costly items various highway agencies have started to consider fuel oil as a special resource that needs to be effectively controlled.

This report presents the results of an ongoing study sponsored by the Federal Highway Administration (FHWA) and Indiana Department of Highways (IDOH) aimed primarily to identify the energy needs in terms of fuel consumed by the equipment fleet for maintaining the state highway system in Indiana. The ultimate goals of this study are to establish improved fuel consumption standards for routine maintenance equipment fleet and to identify possible actions that can achieve both cost and energy savings in routine maintenance.

FUEL CONSUMPTION IN ROUTINE MAINTENANCE OF THE STATE HIGHWAY SYSTEM

There are two categories of energy consumption in highway routine maintenance: (i) direct energy consumption by equipment fleet; and (ii) indirect energy consumption in manufacturing and transporting the materials used in maintenance. In this study, only the first category, direct energy consumption by equipment fleet, was considered.

Inflation and price increase have significantly affected the routine maintenance expenditures for the state highway system in Indiana. For example, the total expenditure on routine maintenance activities in 1976 was estimated as 30 million dollars, while in 1981 this expenditure estimate increased to about 48 million dollars with an average of about 12% yearly rate of increase. This situation is depicted graphically in Figure 1. On the other hand, while the cost of fuel oil consumed in field activities related to routine maintenance in 1976 was about 2.5 million dollars, this cost increased to about 6.0 million dollars in 1981 with an average of 28% yearly rate of increase (Figure 2). In addition, Figure 3 illustrates how the ratio of fuel cost to maintenance materials cost has increased over time; for example, the share of fuel cost of the total material costs in 1976 was 17% as contrasted to 27% in 1981. It should be noted here that the final costs reported here involve only the fuel use by the equipment fleet required to do the field work in maintenance. There costs do not include fuel consumed for transportation of supervisors and other overhead activities.

Fuel oil should be treated as a special resource that needs to be effectively controlled. A careful management of fuel oil cannot be undertaken, however, without detailed information regarding equipment utilization and associated fuel consumption. Many studies were made in the past in the general area of energy use of maintenance equipment (7,8,9,10,11). However, the available information does not provide either the degree of variability of fuel consumption between different equipment types, or the variability of fuel consumption for the same equipment when used in different maintenance activities. Furthermore, the current information of equipment utilization in the IDOH is presented in terms of number of hours or number of miles an equipment is used. These measures are not detailed enough and are not useful unless other supporting rates of consumption are developed. Such rates as miles per gallon (mpg) or gallons per hour (gph) are necessary not only to recognize the amount of fuel consumed, but also to identify the degree of use of a particular equipment.

One of the objectives of this study, as mentioned earlier, is to establish new standards for fuel consumption for different types of maintenance equipment. This information can then be used in an effort to formulate strategies that can achieve improved equipment utilization and thus can save energy and maintenance cost. The results obtained can also be of use to the IDOH in programming of routine maintenance activities.

CURRENT PRACTICE OF PROGRAMMING ROUTINE MAINTENANCE IN THE IDOH

Presently, there are three levels of management in the programming process in the Division of Maintenance in the IDOH: Central Office level, District level represented by district engineer, and the Subdistrict level. At the subdistrict level, the subdistrict manager is responsible for three or four units where equipment is stored. Each unit has a foreman who is in charge of actual field work, and who is responsible for reporting expected maintenance needs.

The programming process may be summarized in the following steps:

1. The subdistrict foreman reports the expected needs of each maintenance activity in terms of number of production units (e.g., lane miles for sealing cracks, tons of bituminous mix for shallow or deep patching, and so on) required in the subsequent fiscal year. These reports are based on a blend of the foreman's visual examination of the different locations under his authority, and records of work performed in the most recent year.

2. Long before the beginning of the fiscal year (e.g., several months), personnel from the central office visit different subdistricts to discuss the needs of each activity. These needs are then converted to a key element in the programming process called QS (Quantity Standard). The QS is defined as the annual quantity of work related to one inventory measure

unit (6). For example, in the shallow patching activity, the inventory is measured by the total number of lane-miles of roadway and paved shoulder, while the production units are given in terms of number of tons of bituminous mixture. A QS value of 1.30 means that, in the average, each lane-mile will receive 1.3 tons of bituminous mix.

3. After these visits, the central office ends up with a QS estimate for all subdistrict-activity combinations. Based on these estimated values and on the current standards related to resource needs, the expected budget for routine maintenance activities for the fiscal year can be estimated. An evaluation of the proposed maintenance program by the maintenance chief and other managers determines whether this plan is accepted or not. If not, adjustments are made to the program through cooperation of the managers from three levels, the headquarters, district, and subdistrict. Such a cycle may then be repeated for several times until a settlement is reached between the maintenance requirements assumed by the subdistricts and the resources available.

It is obvious that the availability of accurate information of various resource needs for maintenance activities is vital to the process of preparing an annual maintenance program. An effective programming of routine maintenance activities is mainly limited by the accuracy of the input information. The IDOH has a system of data collection which has provided good standards for both material and labor. However, the current standards do not

include sufficient information on equipment usage and associated fuel consumption. Referring to Figure 3, it is clear that fuel cost constitutes a considerable portion of the total material costs (about 27% in 1981). A better assessment of fuel costs will certainly help to achieve better allocation of available funds.

STUDY METHODOLOGY AND DATA COLLECTION PROCEDURE

Although the primary objective of this study was to develop new standards for maintenance equipment fuel consumption, it was decided to consider also the calculation of unit costs for the other two resources, material (other than fuel oil) and labor. This was done for two reasons: (i) to update the current material and labor standards, if necessary; and (ii) to determine the share of fuel cost in the total cost of undertaking a routine maintenance activity.

Field data were collected in the present study using the existing system of data recording with some modifications. The current data recording system consists of filing work records on a card called crew day card. Each time a crew performs an activity, all necessary information is recorded on a crew day card. Figure 4 is an illustration of a crew day card. Information recorded on such cards include:

1. Routine maintenance activity type.
2. Location where the activity was performed.
3. Date.
4. Number of crew members and corresponding man-hours.
5. Equipment used and corresponding miles or hours.
6. Materials used and corresponding quantities.

7. Total accomplishment (production units).

Six subdistricts were chosen within the six districts of the IDOH for field data collection. The location of these subdistricts is shown in Figure 5.

The current data recording system does not include any information about the amount of fuel consumed by different equipment types. To provide fuel use data, the subdistrict managers were instructed to fill each equipment with fuel before and after each job. The difference was to be recorded on the same crew day card with other associated activity data.

To avoid bias toward a specific period of the year, the data collection was spread over the entire fiscal year 1981-1982. The year was divided into four basic work seasons: fall, winter, spring, and summer. During a particular season, the data were collected over an extended period. For example, the fall data were collected for about six weeks during October and November, 1981, the winter data in a period of eight to ten weeks between December, 1981 and April, 1982, the spring data in a period of six weeks between April and May, 1982, and the summer data in a period of six weeks between May and July, 1982. By spreading the sample data over the entire fiscal year, it was ensured that those activities with seasonal peaks would be appropriately represented. For instance, about 50% of the total production units of shallow patching activity is accomplished in the spring season, while machine mowing is concentrated in the summer.

The data were subjected to a careful screening process where each crew day card was examined and about 15% of the total sample size was excluded for one or more of the following reasons:

1. More than one activity reported on the same crew day card.
2. Missing information, such as number of gallons consumed by one or more equipment.
3. When obvious recording mistakes were detected.

Table 1 shows the different routine maintenance activities included in the maintenance management system of the IDOH, along with their code numbers and units of measure. Snow and ice removal (activity number 263) was considered separately and will be presented in a separate section at the end of this report.

In Table 2 is shown the sample size (number of crew day cards) for each activity-season combination after the screening process. These numbers are the final observations considered in the analysis. The sample sizes reflect the actual field variation in accomplishing different activities. To illustrate, the actual crew days accomplished in the fiscal year 1981-1982 for activities 201 and 203 for the 6 subdistricts considered in this study were 1277 and 29, respectively. The corresponding sample sizes were 342 and 8 crew days. The variation in applying certain activities in different seasons is also represented in this sample. For example, the actual production of activity 201 in the spring period ranges for 45% to 55% of the total production of

this activity. In the sample about 54% of the total sample size for activity 201 (342 crew day cards) were received in the spring period (185 crew day cards).

Activities 205, 249, 271, 273, 281, and 283 (refer to Table 1 for activity names) are usually recorded on crew day cards. However, these activities are not performed frequently and no data were received for these activities during the entire study period. Furthermore, there are several activities (activities 112, 117, 120, and 900) that are not usually recorded on crew day cards. Consequently, no field information could be obtained for these two groups of activities. Finally, it should be mentioned here that the sample did not include observations for all activity-season-subdistrict combinations. That is, for some activity-season combinations, only some of the six subdistricts provided us with the corresponding crew day cards. This fact was considered in the different statistical comparative studies presented later in this report. The list of equipment used in maintenance activities is shown in Table 3 along with their code numbers. Also listed in Table 4 are the different materials utilized in routine maintenance activities along with their code numbers, units of measure, and unit costs (1981-1982 unit costs). In Table 5, different labor categories are presented along with category code numbers and wage rates (1981-1982 wage rates).

RESULTS OF THE STUDY

The results of this study can be divided into two major groups. The first group was devoted to calculate fuel consumption rates and costs in various routine maintenance activities. In this group, rates of fuel consumption in terms of number of gallons consumed by the equipment fleet to produce one production unit of each activity, and the proportion of fuel cost to other resource costs were identified based on the information obtained from the field sample. Different groups of activities were also analyzed and percentages of cost devoted to fuel were calculated. These results can be used directly by the IDOH Maintenance Division in preparing the annual routine maintenance programs.

In the second group, different factors that affect fuel consumption were analyzed to discover possible sources that may cause deviation from the rates developed in the first group. The effect of such factors as highway type and season (i.e., time of the year when the activity is performed) on fuel consumption was analyzed.

These results were developed mainly for use by the Maintenance Division in the process of evaluating actual field work. Although the average rates can be used to make an estimate of total future needs, an analysis of actual performance of various maintenance activities would require an explicit understanding of the factors that cause variation in fuel use rates.

Calculation of Fuel Consumption Rates and Costs

In this group, fuel consumption rates and costs were computed along with the ratio of fuel cost to total cost or to material cost. Total cost of an activity is defined as the sum of labor, material (other than fuel), and fuel (equipment) costs. Although the IDOH already has very good standards (unit costs) for both labor and material (other than fuel), it was decided to determine these unit costs on the basis of the field sample collected in this study. This way the current rates can be further checked and a uniform and unbiased set of cost data can be developed for the computation of ratios of fuel cost to other resource costs.

Cost Computation Procedure

The general form of cost calculation of an activity is given by:

$$T_k = \sum_i \sum_j f_{ijk} * R_{ijk} * C_{ij} \qquad (1)$$

where,

T_k = total cost in dollars per production unit of the k^{th} activity;

f_{ijk} = usage factor of the j^{th} element of the i^{th} resource when used in accomplishing the k^{th} activity;

R_{ijk} = rate of consumption of the j^{th} element of the i^{th} resource required to produce one unit of the k^{th} activity;

C_{ij} = unit cost of the j^{th} element of the i^{th} resource.

The usage factor, f_{ijk}, is calculated as

$$f_{ijk} = \frac{n_{ijk}}{N_k} \tag{2}$$

where,

n_{ijk} = total number of jobs observed using the j^{th} element of of i^{th} resource in the k^{th} activity;

N_k = total number of jobs in the k^{th} activity.

Finally, the consumption rate, R_{ijk}, is obtained from

$$R_{ijk} = \frac{U_{ijk}}{P_k} \tag{3}$$

where,

U_{ijk} = total number of units of the j^{th} element in the i^{th} resource when used in the k^{th} activity;

P_k = total number of units produced of the k^{th} activity.

The computational procedure can best be illustrated by an example. Consider activity number 201 (shallow patching). The computations of labor, material, and fuel costs for this activity are presented in Table 6.

The usage factor (f_{ijk}, Equation 2) represents the frequency of use of certain resource elements. For example, the usage factor of the first element (j=1) of the first resource (i=1), namely maintenance worker IV, is 5.0. This means that in the 342 jobs of activity 201 (shallow patching) there was a total of about 1710 maintenance workers of category IV, resulting in an average of 5.0. Similarly, in the 342 jobs where activity 201

was conducted (in the sample), a total of 311 dump trucks were used; the corresponding usage factor is therefore 0.91 for the 6^{th} element (dump truck) in the 3^{rd} resource (equipment).

Rate of consumption is the average number of units of certain resource element required to produce one production unit of an activity (R_{ijk}, Equation 3). For example, to calculate the consumption rate of fuel for a dump truck when used in activity 201, the total number of gallons consumed by all dump trucks in the 342 jobs of this activity (U_{ijk}, Equation 3) was calculated and found to be equal to 3640.4 gallons. On the other hand, the total number of activity 201 units produced in the 342 jobs was found to be 1180 tons of mix (P_k, Equation 3). Thus, by applying equation 3, the average fuel consumption rate of a dump truck when used in activity 201 is about 4.78 gallons.

Application of Equation 1 in this example results in a total cost of $114.39 per production unit of activity 201 (1981-1982 unit costs). The fuel cost per production unit is $9.32 and the total materials cost per production unit is $36.62. Therefore, the fuel oil cost, as a single material item, represents about 25% of the total material costs, and nearly 8% of the total cost for shallow patching activity. Using the unit cost figures developed in this study and considering the actual total production in the fiscal year 1981-1982 for shallow patching activity (33,812 tons of mix), the cost of all materials other than fuel oil is about 0.92 million dollars, while the cost of fuel oil only is nearly 0.32 million dollars.

The above calculations were repeated for all other activities considered in this study. A summary of the results is given in Table 7. Also, in Figure 6 is shown a graphical presentation of total costs of different activities. No field observations were available for activities 205, 249, 271, 273, 281, 283, 112, 117, 120, and 900 (refer to Table 1 for activity names). Labor and material costs for these activities were estimated from the current IDOH standards. Not all of these activities are fuel consuming. For those with fuel consumption, the procedure to estimate appropriate consumption rates is described in a separate section of this report under the title "Other Activities".

Figure 7 demonstrates the breakdown of the total cost for each activity into the three cost elements considered in this study, labor, material (other than fuel), and fuel oil. Fuel cost ranges from as low as 3.8% of the total material cost as in the case of activity 224 (seeding and/or fertilizing), and as high as 100% of the total material cost as in the case of activities 211, 212, 221, 222, and so on. (refer to Table 1 for activity names).

High Fuel Consuming Activities

Considering the actual productions for the fiscal year 1981-1982, the top ten fuel consuming activities were identified and are summarized in Table 8. Snow removal and ice control is inherently a high fuel consuming activity. The harsh winter conditions of 1981-1982 made the fuel consumption in this activity

particularly high. In activities such as shallow patching (number 201), crack sealing (number 207), chipping unpaved shoulders (number 213), and spot repair of unpaved shoulders (number 210), the high fuel consumption could be contributed to the high level of stop and go operations of the equipment fleet involved. High fuel consumption in activities 231, 221, and 251 is mostly because of the long distances of travel for the equipment to accomplish the required production. Activities such as 284 and 289 indicate high fuel consumption because these activities involve moving materials and other equipment. Activity 289 particularly involves a high degree of equipment transportation.

The above results clearly indicate the importance of explicitly considering fuel cost in preparing maintenance programs. A detailed estimation of fuel costs may lead to an improved planning and control of maintenance programs.

Fuel Consumption for Different Maintenance Groups

In addition to investigating the individual activities, maintenance managers also examine activities in an aggregate form in which different sets of activities are grouped together based on a particular common criterion. The first type of grouping is based on type of work. For instance, there is a category of activities,defined as roadway and shoulder activities. Another category is labelled as roadside activities, and so on. Activities are usually grouped into eight categories as shown in Table 1. Figure 8 presents the total maintenance costs for the eight

groups, while Figure 9 shows the breakdown of total costs into labor, material (other than fuel), and fuel . It can be seen that the labor cost is the major item in all routine maintenance groups. Fuel cost tends to be less than that of other materials in groups 1, 5, and 6, while the fuel cost proportion tends to be equal or greater in groups 2, 3, 4, 7 and 8 (refer to Table 1 and Figure 8 for category names).

Another type of grouping of routine maintenance activities is based on work control category. The following is a summary of the four work control categories considered by the IDOH.

1. Overhead activities - include overhead and public service activities such as rest area attendant, standby time, training, and maintenance field supervision.

2. Unlimited activities - include activities which are to be performed when needed and in the amount required to correct the deficiency.

3. Limited activities - include activities for which quantities can be established and firmly adhered to.

4. Variable activities - include activities where the amount of work is not urgently needed each year. The planned work is desirable but it is not critical if all of the planned work is not completed during any one year.

The list of activities within each of the above categories are given in Table 9. Total costs for these categories are

presented in Figure 10, while the portions of these costs assigned to labor, material (other than fuel), and fuel oil are shown in Figure 11. About 9% of the total costs are due to fuel oil in category number 1 (overhead), whereas 14%, 13%, and 10% are the corresponding percentages for unlimited, limited, and variable categories, respectively.

So far we have presented a review of total cost and various resource costs for different activities as well as for different groups of activities. We have been primarily concerned with the fuel consumption rates and costs. These rates were developed based entirely on field observations made at different locations (subdistricts), at different highway types (Interstate and Other State Highways), and in different seasons.

Factors Affecting Fuel Consumption

In the following, different factors that influence fuel consumption are discussed. This analysis was done in order to provide further insights that may help in evaluating fuel consumption records of different subdistricts or districts in undertaking different maintenance activities. To this end, we considered the following two major factors that affect the fuel consumption rates in maintenance activities:

1. Frequency of use of individual equipment.

2. Consumption rate of individual equipment.

The effect of highway type and of season on each of these factors will also be discussed.

Equipment Frequency of Use

The usage factors (f_{ijk}, Equation 1) for all activity-equipment combinations were computed. Shown in Table 10 is a list of all equipment that were found to be used in each activity (with crew day cards available in this study) along with their corresponding usage factors. For instance, the usage factor of equipment number 9 (dump truck) when used in activity 201 (shallow patching) is 0.91, 1.90 for activity 202, and so on.

Several cases were studied to determine whether the frequencies of equipment use in Interstate (IS) highway system differ from those in Other State Highways (OSH). A close examination of the usage factors developed from the observed data from the two highway types indicated a good agreement. It can be concluded, therefore, that frequency of use of an equipment is independent of highway type.

The next analysis of equipment usage was carried out to examine the variation between subdistricts. It was observed that the frequency of equipment use can be significantly different from one subdistrict to another. In fact, this is true in more than 50% of the activities. However, for the purpose of illustration we consider here five most frequently undertaken activities. Four of these five activities are also among the top ten fuel consuming activities (refer to Table 8). These activities

are 201, 227, 231, 251, and 276 (refer to Table 1 for activity names). For each activity we chose the most frequently used equipment (highest usage factor). The results concerning the usage factors for the different cases considered are illustrated in Figures 12 to 16.

It is obvious from these Figures that the frequency of use of an equipment can vary significantly from one subdistrict to the other, and the individual values for each subdistrict can also differ considerably from the total average. To illustrate, consider the case of activity 201, as shown in Figure 12. The usage factor for a dump truck when used in subdistrict number 1 (refer to Figure 5 for subdistrict locations) is 1.20, whereas it is 0.42 for subdistrict 4 and 1.50 for subdistrict 6. Similar results can be seen for other four cases, as shown in Figures 13 to 16. There are also other numerous cases that indicate a variation between subdistricts in their degree of equipment usage frequency. This fact should be kept in mind in the evaluation process, as this variation can greatly affect the total number of gallons per production unit of an activity.

The last factor that was investigated is the season (time of year when an activity was performed). The same activity-equipment combinations used in the previous analysis (Figures 12 to 16) were utilized in the present analysis.

The main conclusion arrived at in this analysis is that equipment usage factors vary in many cases from season to season.

This is mainly because the availability of an equipment for a given activity is limited by the competition between several activities being undertaken during the same season. For example, considering activity 201 (shallow patching), the usage factor of a dump truck is less in winter than in summer (see Figure 17). This is because during the winter months the use of the available dump trucks for snow removal and ice control is given higher priority over other activities. The variation in other equipment usage factors by season is illustrated in Figures 18 to 21.

To summarize, the frequencies of equipment use may vary significantly from one subdistrict to another. This may be due to the availability of certain equipment types in a subdistrict or due to differences in field techniques employed by subdistrict foremen. Also, the difference in equipment usage by season may be significant in many cases. In addition, we observed no difference in equipment usage of an activity performed on Interstate or Other State Highway Systems.

Rates of Equipment Fuel Consumption

Rate of fuel consumption of an equipment when used in an activity is defined as the number of gallons consumed by this equipment to accomplish one production unit of the activity. The summation of these rates for all equipment used in an activity will result in the overall rate of fuel consumption for the particular activity. These rates (gallons per production unit) have been presented in Table 7.

Consumption rates of an equipment usually vary from activity to activity. This is usually so because of the difference in the nature of work conducted by the same equipment in different activities. A good factor to analyze such differences is the equipment operational rates related to fuel consumption, such as miles per gallon (mpg) or gallon per hour (gph). For example, in Figure 22 are shown the operational rates for a pickup truck when used in different activities, while Figure 23 and Figure 24 show similar results for a dump truck and a loader, respectively. The three equipment types, pickup truck, dump truck, and loader, were chosen as examples; however, the available data would allow an analysis of this pattern of variation for any other equipment types. Rates of fuel consumption by different equipment in terms of gallons per production unit of each activity are shown in Table 11 along with the corresponding operational rates of fuel consumption (miles per gallon or gallons per hour). From Figures 22 to 24 and from the information given in Table 11, it is obvious that an assumption of equal operational rates for a maintenance equipment in different activities can be misleading.

To illustrate, consider Figure 24 where the loader operational rates are shown. In activity 202 (deep patching), 0.94 gallons per hour is the operational rate, contrasted to 2.67 and 2.13 gallons per hour for activity 212, and 234, respectively. It is clear that the work conducted by a loader in activity 202 is much simpler than that performed in activity 212 or 234, where more gallons per hour are consumed. Same remarks apply to the

other two examples (Figures 22 and 23) where more miles per gallon indicate less idling involved in the work.

Other important rates such as average miles per production unit, or average hours per production unit are provided in Table 12. Such information along with other rates (miles per gallon or gallons per hour) can be useful in the maintenance field work evaluation process.

The first analysis on operational rates of fuel consumption was to examine if these rates differed by type of highway. A relatively small number of data observations was available for jobs done on Interstates. This is because the number of units accomplished in most activities in the Interstate system is much less than that carried out in Other State Highways system (OSH). This can be confirmed by the fact that only 10% of the total routine maintenance expenditures in 1981-1982 was for the Interstate system (14).

The limited available data for the Interstate system did not cover all activity-equipment-highway type combinations. Only 20 separate statistical tests were therefore applied. Each test is defined by the season, activity number, subdistrict number and equipment number. A list of these tests is shown in Table 13. The reason for considering the above elements in defining each test is to eliminate the effect of factors other than highway type. So, in each test the operational rates of an equipment type in both Interstate and Other State Highways were statisti-

cally compared, and the results are reported in the last column in Table 13. A "Yes" means that average values of operational rates in the two systems is significantly different at a level of confidence of 90% or 95%. The results of the tests are graphically presented in Figure 25. To illustrate, consider test number 15. This test was to compare the output rates (mpg) of a dump truck (equipment number 9) for shallow patching (activity number 201) on Interstate and Other State Highways within the subdistrict number 5, performed in spring season. It was found that the average operational rates on the two highway systems are significantly different. It is clear that the general trend is a higher rate of fuel consumption on Interstate systems. Out of 20 tests, 17 tests indicated a significant difference between the two highway systems with a higher fuel consumption rate for the Interstate system.

It should be noted that the results are based on relatively small number of Interstate observations and not all activities were covered by the comparison tests. However, the results point out the importance of a careful study of the management units (subdistricts) that have a large portion of Interstate mileage in their highway system. These subdistricts may tend to use more fuel in their operations than those with low amount of Interstate mileage.

The second analysis was carried out to investigate the effect of the time of year (season) on equipment fuel consumption rates. This is the effect of season on the number of miles per

gallon or gallons per hour consumed by an equipment when used in an activity. The approach adopted in this analysis was identical to that of the previous analysis. Statistical comparison tests were employed to test if the equipment operational rates were actually affected by the season. Each test is defined by the activity, subdistrict, equipment, and two seasons to be compared. A total of 138 tests were applied in this analysis. A list of these tests is given in Table 14. Tests 1 through 42 were used to compare fall and winter seasons, tests 43 through 96 to compare fall and spring, tests 97 through 129 to compare fall and summer, and tests 130 through 138 to compare spring and summer. For example, consider test number 10. This test was used to compare the miles per gallon consumed by a dump truck in fall and winter seasons, for activity 207 performed in subdistrict number 2. The test indicated that the average fuel consumption rates of a dump truck during these two seasons for crack sealing are significantly different, with a higher fuel consumption rate in winter.

Graphical illustrations of the four test groups mentioned above are presented in Figures 26 to 29. In comparing the fall versus winter seasons 31 out of 42 tests showed a significant difference between the two seasons (indicated by "Yes" at the last column in Table 12), with higher rates of consumption in winter, at a confidence level of 90% or 95%. Stated differently, less miles per gallon or higher gallons per hour can be expected when an equipment is used to perform a particular activity in

winter than in fall.

Fifty-four tests were applied to compare fall and spring. Out of the 54 tests, 40 tests indicated a significantly higher fuel consumption rate in spring than in fall.

For the comparison between fall and summer, 19 out of 33 tests showed no significant difference between the two seasons, 9 tests indicating a higher consumption rate in summer, and 5 tests with a higher rate in fall. Consequently, no clear trend could be established for this group.

The last comparison was between spring and summer. Out of 9, 7 tests indicated a higher fuel consumption rate in spring than in summer.

Reviewing the results of the four test groups, it can be concluded that the rate of fuel consumption by an equipment fleet is higher in winter and spring seasons than in fall and summer. However, the degree of that difference may vary between activities. A general conclusion is that for the comparison of the consumption rates a year can be divided into two basic periods, the first including winter and spring seasons, and the second including fall and summer seasons. Jobs executed in winter and spring seasons were observed to consume more fuel than those performed in fall and summer seasons. Furthermore, fuel consumption rates are affected by highway type. More fuel consumption can be expected for jobs carried out in Interstate system than for jobs in Other State Highway system.

The process of evaluation of fuel consumption of various equipment types can be achieved through a proper sampling procedure that covers different activity-subdistrict combinations. The list of equipment types observed to be used in each activity was presented in Table 10. Although a relatively large number of equipment types are associated with different activities, only a few of them contribute most to the total fuel consumption. To illustrate. The case of activity 201 (shallow patching) can be considered. From Table 10 it can be seen that there are 16 different equipment types are associated with this activity. In fact, 82% of the total fuel consumption (8.88 gallons per ton of mix, Table 7) are consumed by two equipment types, dump truck and pickup crew cab. Consequently, a sampling procedure would not require a large field sample, because only dominant fuel consuming equipment types can be included in the field survey. In the case of activity 201, dump truck and pickup crew cab are dominant equipment types. Table 15 shows the fuel intensive activities along with their dominant equipment types and the corresponding shares of the total fuel consumption. The share of an equipment type of the total fuel consumption for an activity is calculated as:

$$S_{ij} = f_{ij} * \frac{R_{ij}}{C_i} * 100 \qquad (4)$$

where,

S_{ij} = the share of equipment type j in the total fuel consumption of activity i.

f_{ij} = usage factor of equipment type j when used in

activity i (Table 10).

R_{ij} = consumption rate (gallons per production unit) of equipment type j when used in activity i (Table 11)

C_i = total fuel consumption (gallons per production unit) of activity i (Table 7).

For example, the share of a dump truck when used in activity 201 is:

$$S_{ij} = \frac{0.91*4.78}{8.88} * 100 = 49\%$$

Controlling the usage of dominant equipment types can lead to an overall control of fuel consumption in routine maintenance activities.

SNOW REMOVAL AND ICE CONTROL (ACTIVITY 263)

The snow removal and ice control activities represent a significant portion of the routine maintenance work load, and therefore these activities require particular attention in the process of routine maintenance budget preparation. At the national level more than half billion dollars are spent yearly in highway snow removal and ice control activities (12). In Indiana, more than 14 million dollars were spent last winter in highway snow removal and ice control (14). About 16% of this total cost can be attributed to fuel cost (Table 7).

In this section, we present the results of the study concerning the development of fuel consumption rates for snow removal and ice control activity.

Current Practice of Snow Removal and Ice Control in Indiana

Snow removal and ice control is a very unique activity which should be considered carefully in a routine maintenance planning process. Apart from the fact that a considerable portion of resources is required for this activity, snow removal and ice control activity is also a direct factor in highway safety.

The highway network of any management unit (such as a subdistrict) includes a set of snow routes. Each route consists of one or more segments of the existing roadways. A route could be classified as Class I, Class II, or Class III route. There are two reasons for classifying state highways. First, classifica-

tion provides a means of establishing relative priorities for providing service. Second, classification provides a means of establishing acceptable roadway conditions. Generally, higher classification roads (Class I) receive more service than a road in a lower classification (Class II, and III). The three route classes are defined as:

Class I: those routes which serve as major traffic arteries in and between traffic generation points including Interstate, their associated ramps, and other state routes with traffic volume generally greater than 5000 ADT.

Class II: those routes which serve as intermediate collectors with traffic volume generally between 1000 ADT and 5000 ADT.

Class III: all other state routes not included in Class I and Class II with traffic volumes generally less than 1000 ADT.

As mentioned above, one purpose of route classification is to assure a certain level of service associated with each class in case of winter emergency. The following is a description of the levels of service desired for each route class.

Class I: Provide continuous service to blade snow and ice from pavement surface and shoulders and apply chemicals and abrasives as needed to provide a wet and reasonably bare pavement.

Class II: Provide continuous service to blade snow and ice

from pavement surface and shoulders. Chemicals and abrasives will be applied as needed to obtain a bare wet pavement in center portion (one wheel path) of the roadway. Final clean up will be deferred to normal working hours.

Class III: Provide minimum service to keep these routes passable. Chemicals will be used only for spot treatment of hills, curves, and intersections in cleanup operations. Final cleanup will be accomplished during normal working hours.

Data Collection Procedure

The six subdistricts were contacted to get the fuel data related to snow removal and ice control, as explained earlier in this report. Only three subdistricts responded. However, it is believed that the data obtained from the three subdistricts (number 4, 5, and 6) are sufficient to develop realistic rates of fuel consumption. The location of these subdistricts cover both northern and southern parts of Indiana. Also, the data obtained for each subdistrict covers all snow falling conditions, from very light (less than 0.5 inches) to very heavy (greater than 10 inches). Moreover, the data obtained cover all route classes with a reasonably large number of observations (more than 1000 observations).

Number of gallons consumed during the service of a certain route was determined by filling each truck before and after the

service, and the difference was then recorded on the snow and ice removal crew day card. The returned cards were carefully reviewed and several cards were not considered in the analysis because they included more than one route (with different classes). Each card was to carry information for a specific route Class (I, II,or III). This screening process ensured consistency in the analysis.

The planning for snow removal and ice control activities depends mainly on the annual climatological data obtained from the Environmental Data Service of the National Oceanic and Atmospheric Administration. On the basis of this information the expected levels of snowfall at different locations in Indiana are estimated. The IDOH has a well developed procedure to estimate the number of man-hours required to serve the roads network under given levels of expected snowfall. The present study would complement the current procedure by providing fuel consumption rates in terms of number of gallons per man-hour. Such rates can then be used to estimate the amount of fuel required during the winter period under given levels of snowfall.

Fuel Consumption Rates in Snow Removal and Ice Control

The results of this phase of the study were used to develop fuel consumption rates in terms of number of gallons per man-hour. These rates can be used by the IDOH in predicting both the amount and cost of fuel oil required to run the equipment fleet used in snow removal and ice control activity (activity number

263).

Two equipment types are used in such activity: trucks to remove snow and loaders. Using equation 2, the rates of fuel consumption in terms of gallons per man-hour were developed for each route class. Table 16 presents a summary of these results. In Figure 30 is shown graphically the fuel consumption rates developed for trucks used in snow removal and ice control activity.

It is obvious from the results presented in Table 13 and Figure 30 that consumption rates for subdistrict number 4 (Monticello) were higher than for other subdistricts. This is not surprising since the amount of snowfall in northern Indiana is usually more than that in the south. For the same reason consumption rates in subdistrict number 5 were found to be higher than those for subdistrict number 6.

When analyzed by route class, the consumption rates were observed to be generally high for higher class routes. This result is as expected because higher class routes require additional service (work) to be done by the equipment.

The total weighted average for fuel consumption for the three subdistricts was found to be 5.0 gallons per man-hour. In winter of 1981-1982, 431,926 man-hours were consumed in snow and ice removal activity on state highways in Indiana. Applying the above average rate of consumption, a total of 2.70 million dollars can be estimated to be the amount spent on fuel oil used to

run the equipment fleet in snow and ice removal activity in 1981-1982. This cost represents about 38% of total fuel cost spent in all routine maintenance activities in 1981-1982 fiscal year. This fuel cost also represents about 17% of the total cost, and about 22% of total material costs for snow removal and ice control in 1981-1982 fiscal year.

The equipment fuel consumption rates developed for snow removal and ice control activities by route class and by subdistrict can be used in the planning and control of winter activities. Management units with higher expected snowfall rates and larger portions of higher class routes can be expected to consume more fuel than other units. This type of information can be useful not only in allocating maintenance budgets by activity and by subdistrict, but also in making evaluation of the actual work performed by various subdistricts.

OTHER ACTIVITIES

It is important to note that only those routine maintenance activities for which crew day cards are available were included in the study. For instance, activities 112, 117, 120, and 900 (refer to Table 1 for activity names) are included in the maintenance management system of the IDOH. However, no crew day cards are issued for these activities. Out of the four activities, only activity number 112 (field maintenance supervision) is a fuel consuming activity. There is no direct way to estimate the fuel consumption rate for this activity. It is suggested that separate field investigation for this activity may be conducted. The total fuel cost presented in this report does not include any estimation for fuel cost in this activity.

There are several activities that are generaly recorded on crew day cards but were missing in the field sample obtained in this study. This could be due to the conflict between the time of application of these activities and the time periods when the field sample was obtained from the six subdistricts. These activities are: 205, 249, 271, 273, 281, and 283. However, in order to present a complete data base, certain assumptions were made as to the resource requirements for these activities. Labor and material (other than fuel) costs for these activities were obtained directly from the current IDOH standards. Fuel costs were then estimated for each of these activities. These estimates were based on the expected similarity in equipment usage in these activities and other activities for which data were

available.

The estimated fuel consumption rates for these activities are included in Table 7. The procedure for estimating these rates are shown in Table 17.

SUMMARY AND CONCLUSIONS

This report has presented the results of a study aimed at the identification of fuel consumption by the equipment fleet used in highway routine maintenance activities in the State of Indiana. Two basic groups of results were considered: (i) the fuel consumption rates for all possible activity - equipment combinations as well as total fuel consumed per production unit of each activity; and (ii) the effect of factors such as location (subdistrict),highway system type,and season on fuel consumption rates. The first group of results will be of direct use to the Indiana Department Of Highways (IDOH) in the planning of the annual maintenance program, while the second group will be useful in evaluating the actual field work of different management units (subdistricts).

Based on the findings from this study, the following conclusions can be made:

1. Motor fuel can be considered to be the most expensive single material used in routine maintenance activities. It is estimated that about 12% to 13% of the total maintenance costs can be assigned to fuel only. Considering the material costs, 26% to 27% can be assigned to fuel.

2. Routine maintenance activities in winter and emergency groups consumed about 43% of the total fuel use in 1981-82. The next highest consumption took place in activities in roadway and shoulder group, where about 19% of total fuel was consumed during the same year.

3. Considering the different work control maintenance groups, the unlimited activities group consumed about 63% of total fuel use in the study year.

4. A major contributing activity in total fuel consumption in routine maintenance is snow removal and ice control. In 1981-82 about 38% of the total fuel used in routine maintenance was consumed in this activity.

5. The frequency of equipment use was found to be significantly different by location (subdistrict) in at least 50% of the total number of activities. The reason for this variation may be partly due to the lack of availability of proper equipment in various subdistricts. Unavailability of adequate equipment would obviously affect the fuel use rates.

6. The frequency of use was found to be considerably different from season to season. On the other hand, no significant difference was detected in the frequency of equipment use between Interstate and Other State Highway systems.

7. The assumption of a standard fuel consumption rate for a given type used in different activities was found to be erroneous. It was observed that the majority of equipment types have considerably different rates of fuel consumption when used in different activities.

8. Although only a few observations were obtained from the Interstate system, it was found that there is a general trend of a higher fuel consumption rate in jobs done in the Interstate system than those done in Other State Highway system.

9. In general, more fuel is consumed in jobs done in winter and spring than in those done in summer and fall.

10. It was found that an average of 5.0 gallons was consumed per man-hour for snow removal and ice control. Fuel consumption rate for this activity for Class I routes was found to be higher than that in Class II, and the rate for Class II routes was higher than that for Class III routes.

Based on the findings presented above, it is recommended that appropriate information should be incorporated in maintenance data recording system. It should be noted that the present study did not include any cost related to equipment depreciation. Equipment repair and maintenance costs are, however, included in activity number 281. An equipment management system is currently being implemented by the IDOH that will address various aspects of overall equipment management in the state highway agency.

It is further recommended that a disaggregate fuel consumption information for each equipment-activity combination be used in maintenance planning. This procedure will help to prepare an improved annual routine maintenance program.

ACKNOWLEDGEMENTS

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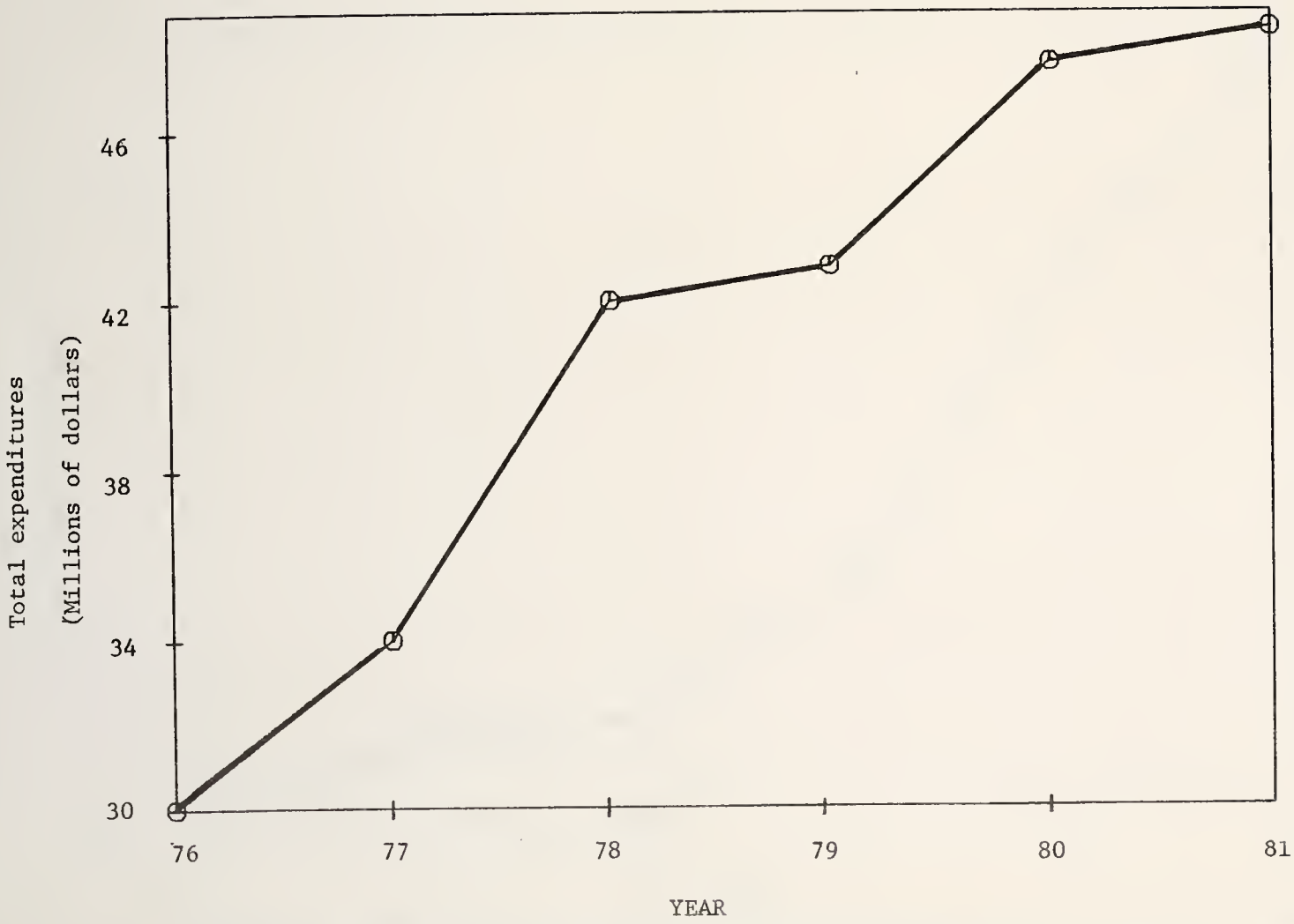


Figure 1: Estimated Total Routine Maintenance Expenditures in the State of Indiana (Current Dollars)
Source : References 4 and 5 and Final Results of this study.

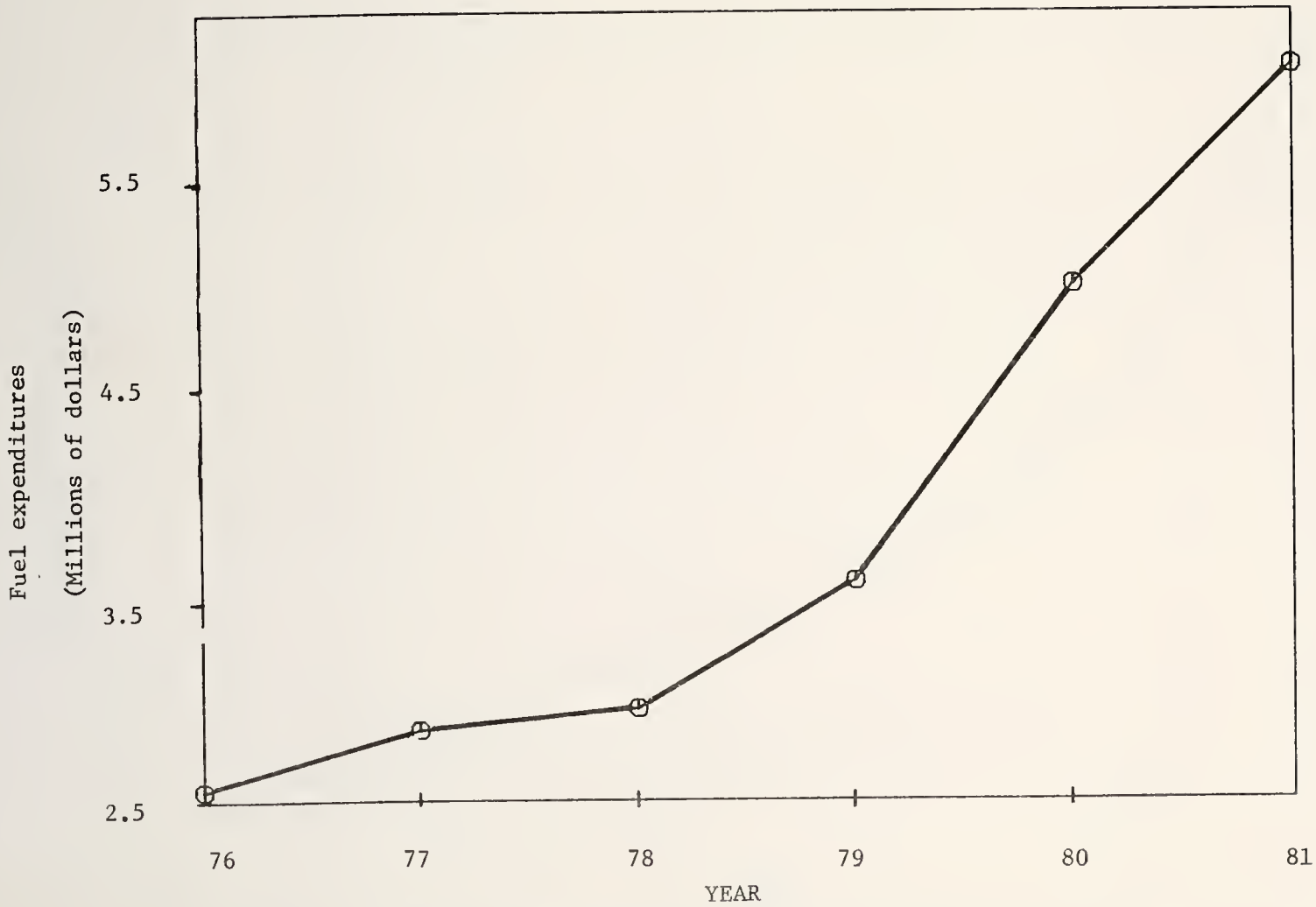


Figure 2: Estimated Fuel Expenditures in Routine Maintenance Activities in the State of Indiana
Source : Reference 4 and 5 and Final Results of this study.

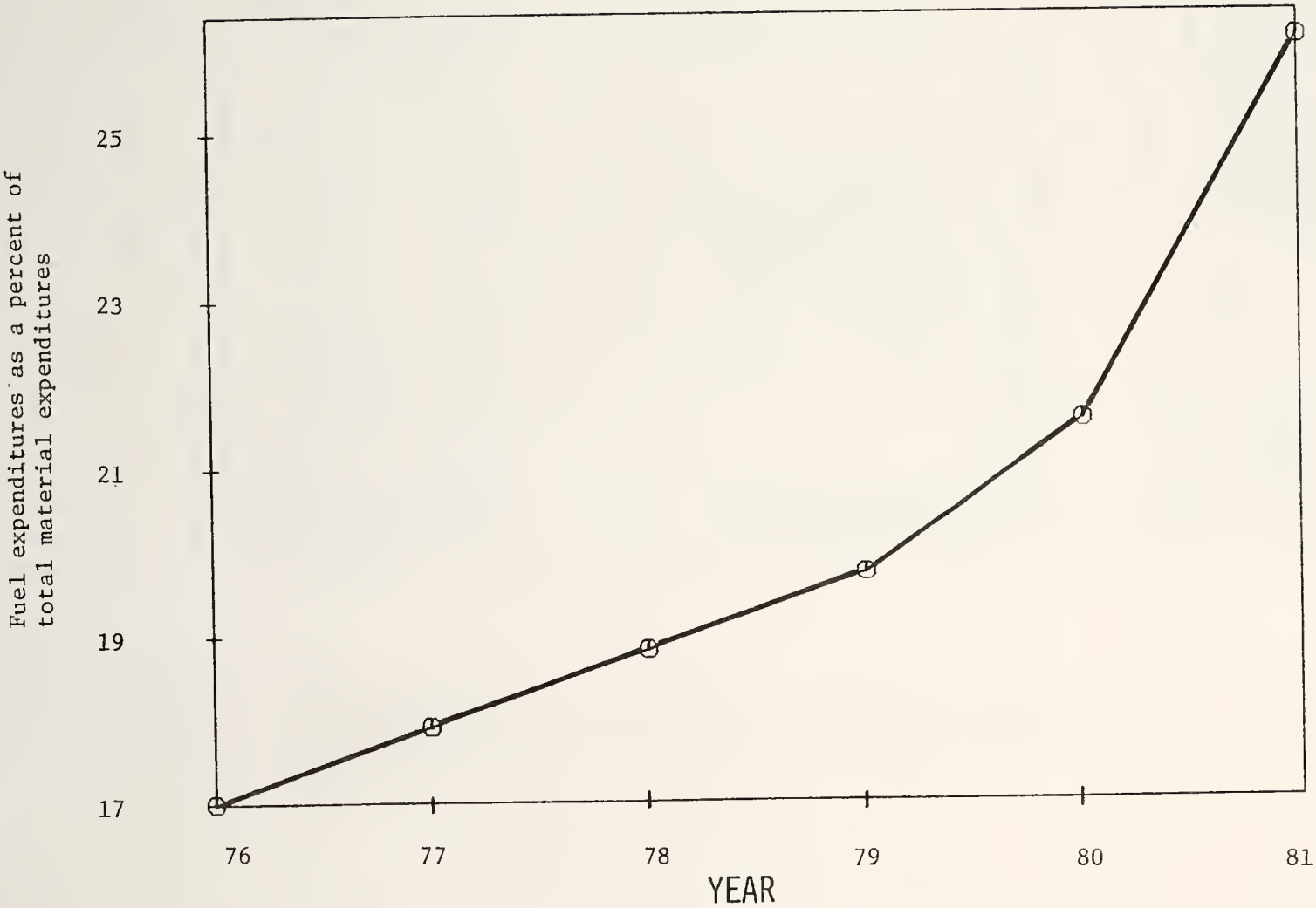
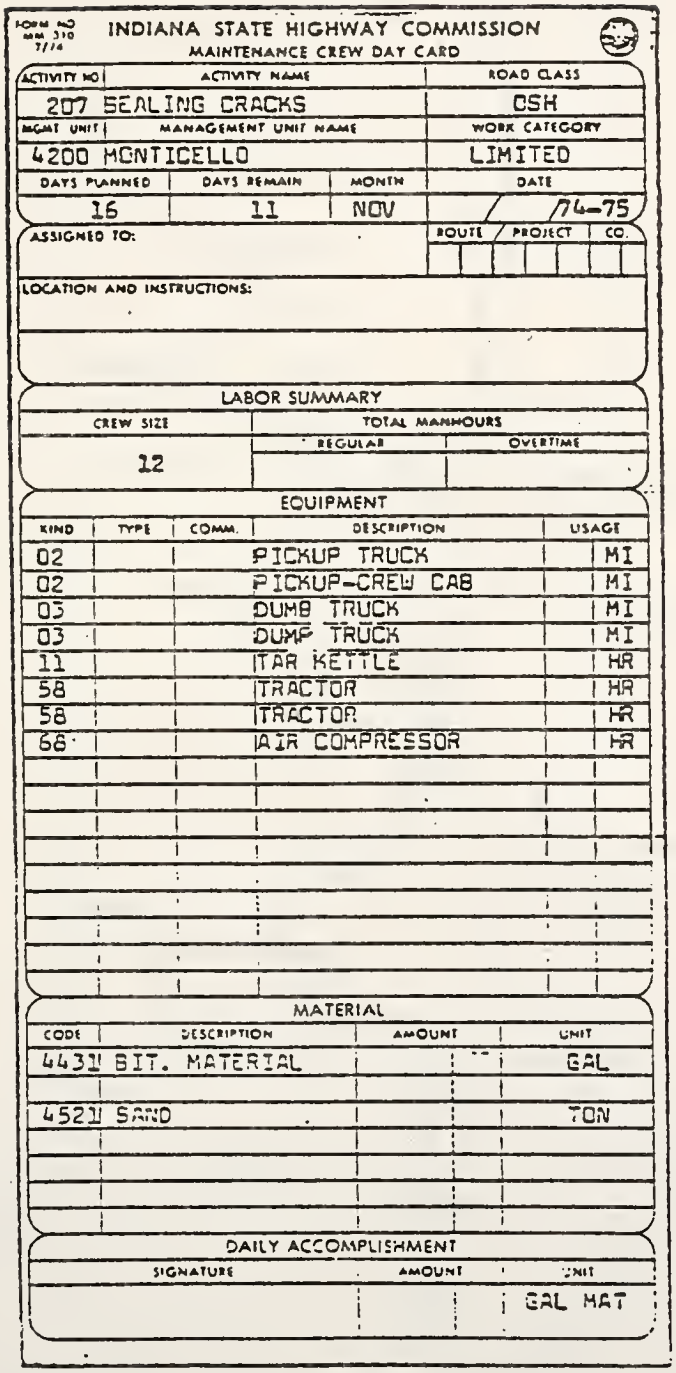


Figure 3: Share of Fuel Expenditure in Total Material Expenditures.
Source : References 4 and 5 and Final Results of this study.



FORM NO MM 310 7/74

INDIANA STATE HIGHWAY COMMISSION

MAINTENANCE CREW DAY CARD

ACTIVITY NO	ACTIVITY NAME	ROAD CLASS
207	SEALING CRACKS	OSH

MGMT UNIT	MANAGEMENT UNIT NAME	WORK CATEGORY
4200	MONTICELLO	LIMITED

DAYS PLANNED	DAYS REMAIN	MONTH	DATE
16	11	NOV	/74-75

ASSIGNED TO:

ROUTE	PROJECT	CO.

LOCATION AND INSTRUCTIONS:

LABOR SUMMARY

CREW SIZE	TOTAL MANHOURS	
	REGULAR	OVERTIME
12		

EQUIPMENT

KIND	TYPE	COMM.	DESCRIPTION	USAGE	
02			PICKUP TRUCK		MI
02			PICKUP-CREW CAB		MI
03			DUMB TRUCK		MI
03			DUMP TRUCK		MI
11			TAR KETTLE		HR
58			TRACTOR		HR
58			TRACTOR		HR
68			AIR COMPRESSOR		HR

MATERIAL

CODE	DESCRIPTION	AMOUNT	UNIT
4431	BIT. MATERIAL		GAL
4521	SAND		TON

DAILY ACCOMPLISHMENT

SIGNATURE	AMOUNT	UNIT
		GAL MAT

Figure 4. Illustration of a Crew Day Card

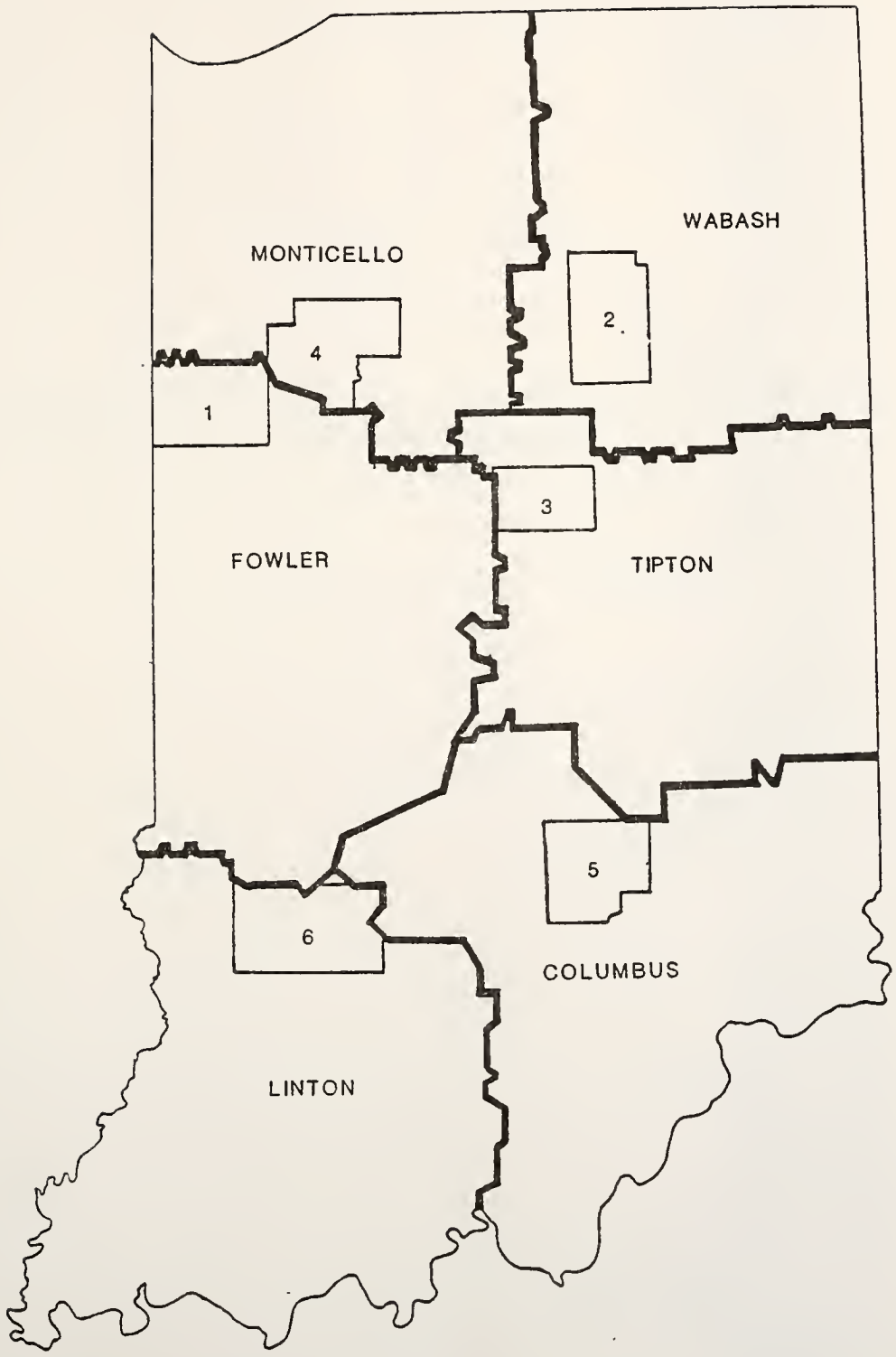


Figure 5. Locations of Subdistricts Included in the Study

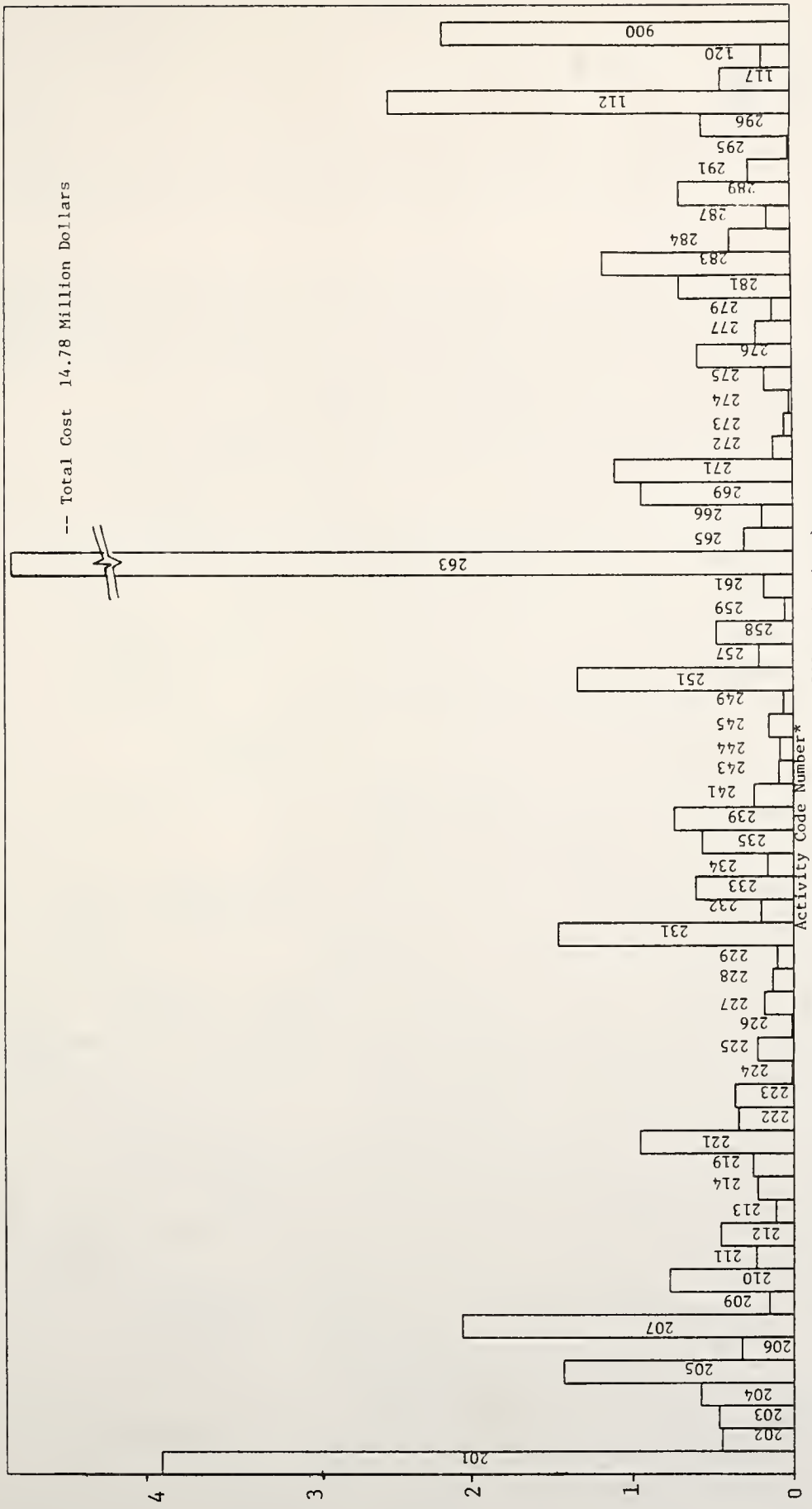


Figure 6 : Estimated Total Costs for Routine Maintenance Activities (1981-1982 Productions)
* Refer to Table 1 for Activity Names

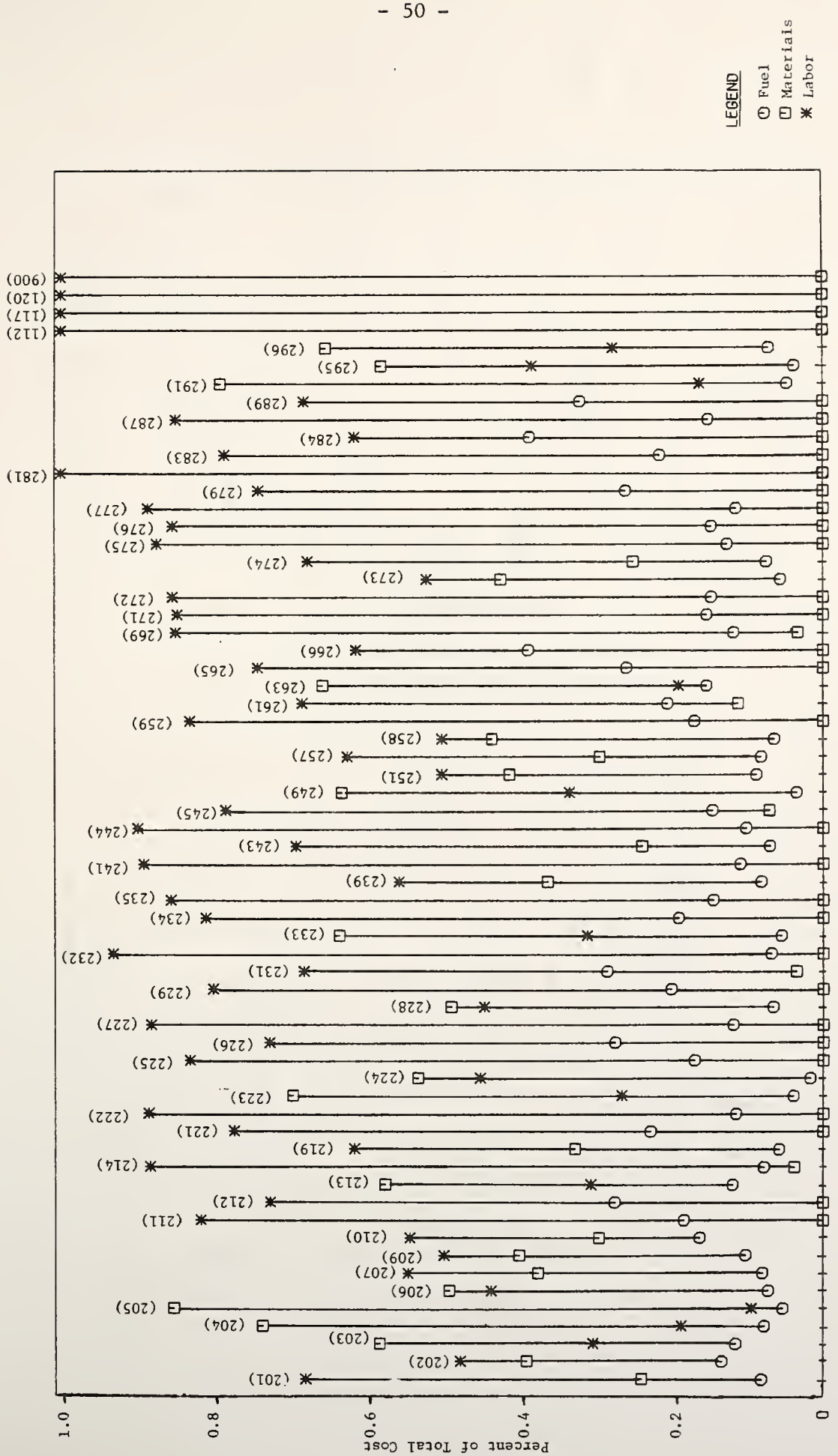


Figure 7: Breakdown of Activities' Total Costs.

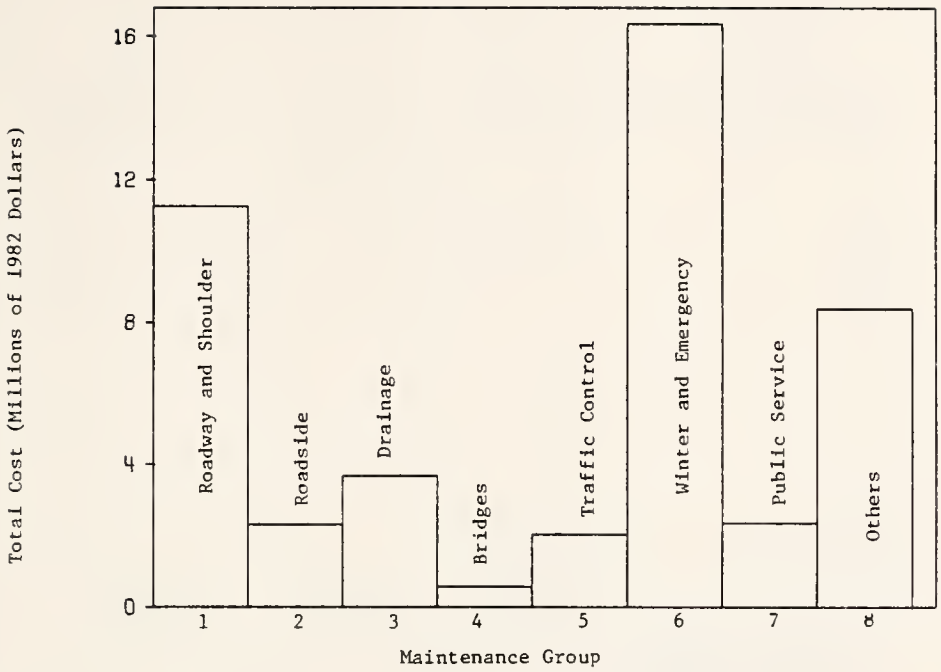


Figure 8: Total Costs for Different Maintenance Groups

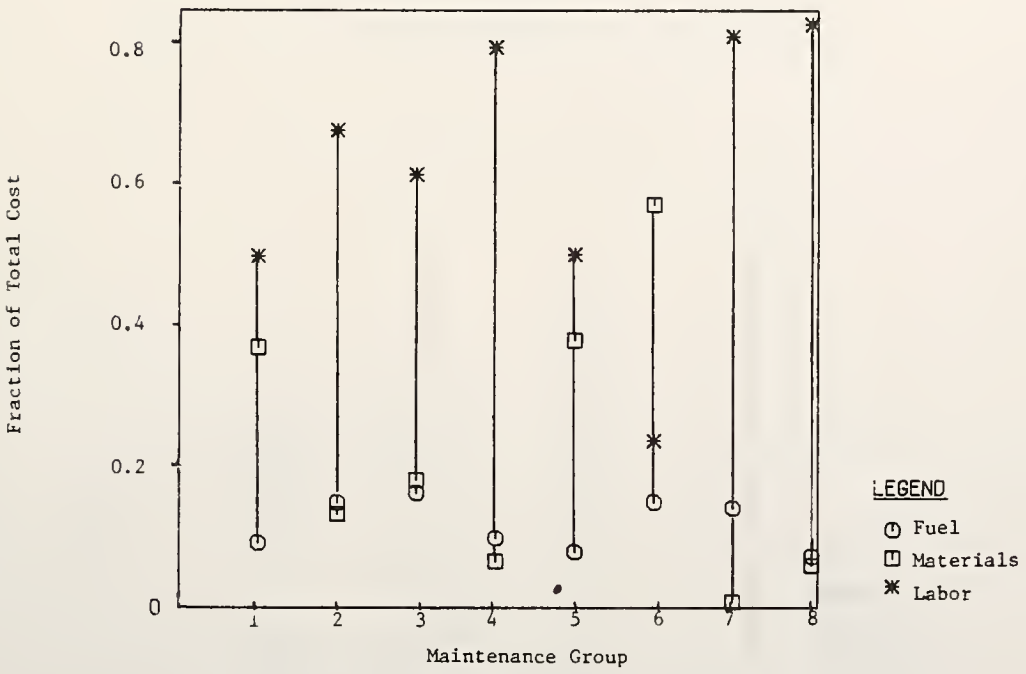


Figure 9: Breakdown of Maintenance Groups' Total Costs

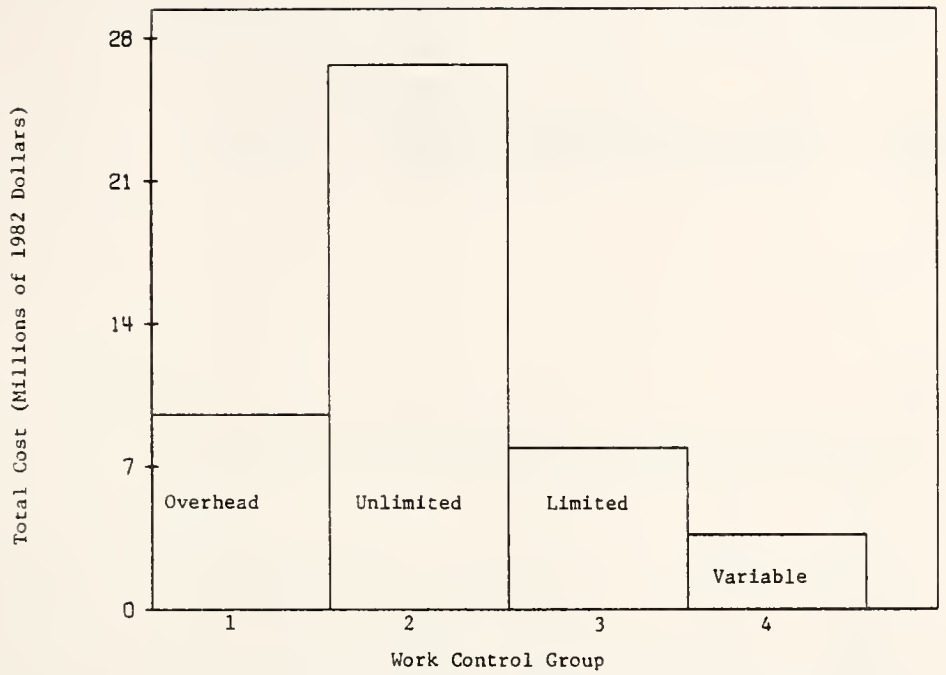


Figure 10: Total Costs for Different Work Control Groups.

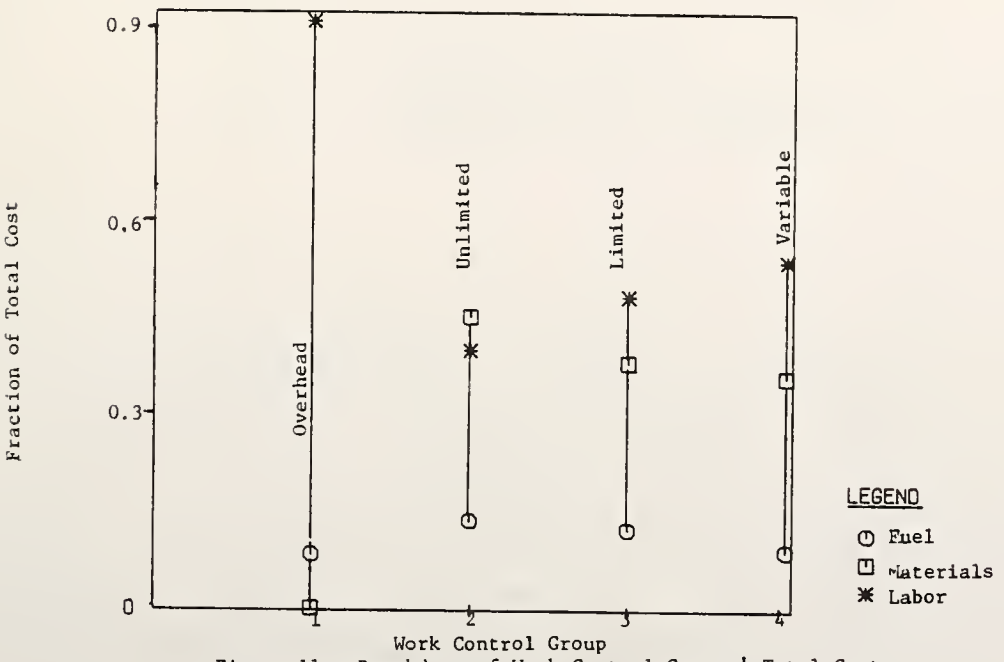


Figure 11: Breakdown of Work Control Groups' Total Costs.

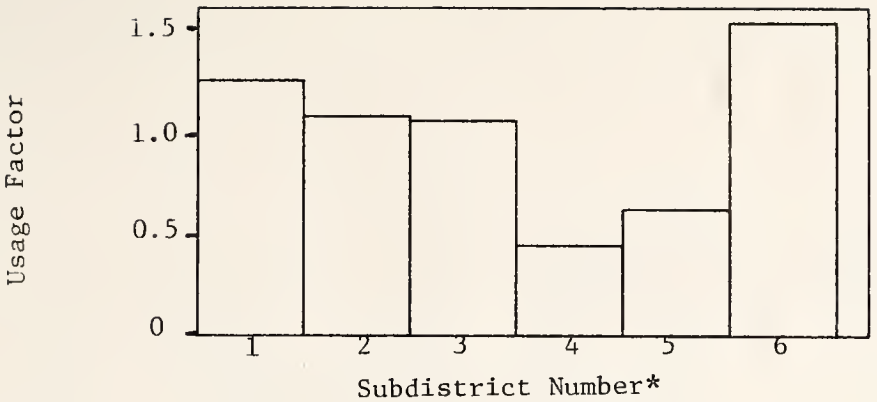


Figure 12: Usage Factors for Dump Truck - Shallow Patching Combination (by Subdistrict)

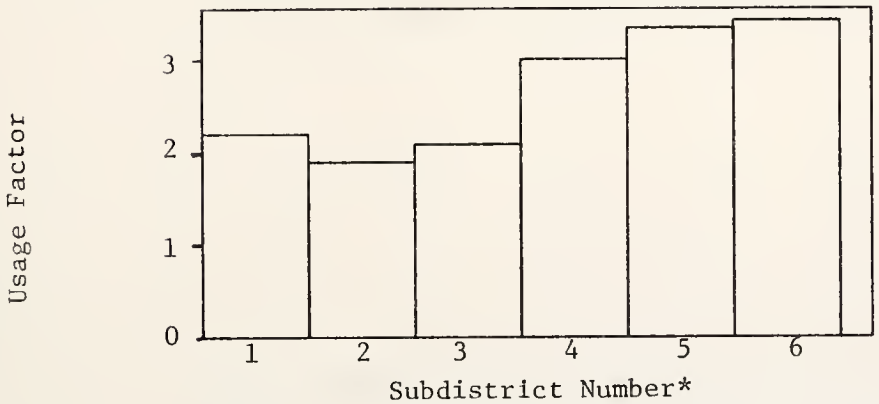


Figure 13: Usage Factors for Tractor Truck - Machine Mowing Combination (by Subdistrict)

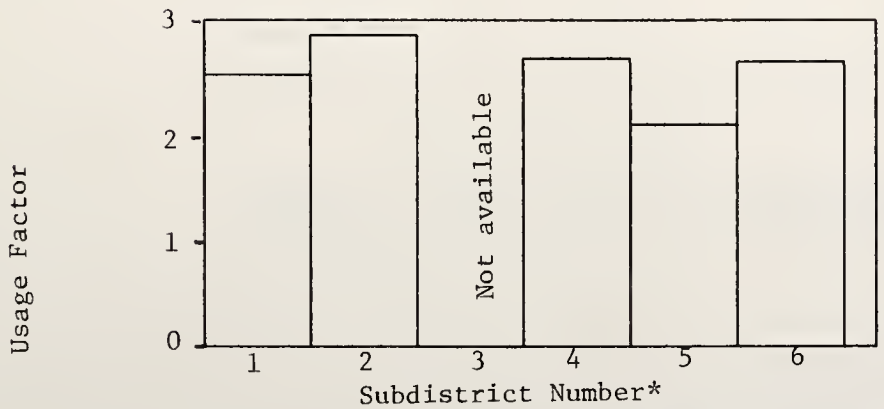


Figure 14: Usage Factors for Dump Truck - Cleaning and Reshaping Ditches Combination (by Subdistrict)

* Refer to figure 5 for subdistrict names and locations.

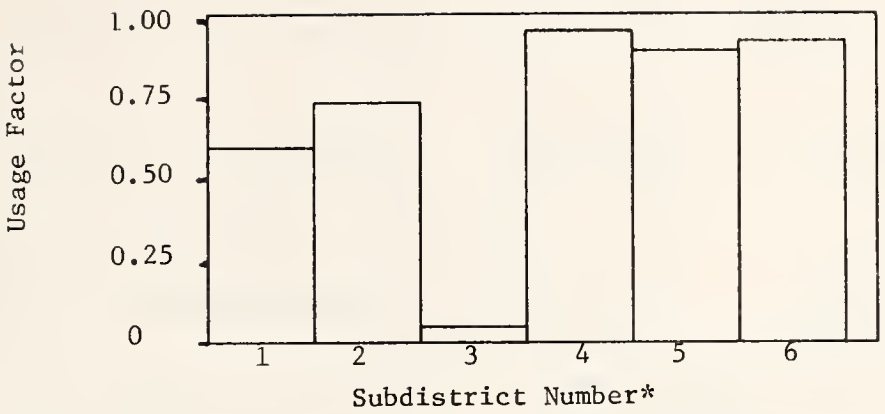


Figure 15. Usage Factors for Utility Truck - Sign Maintenance Combination (by Subdistrict)

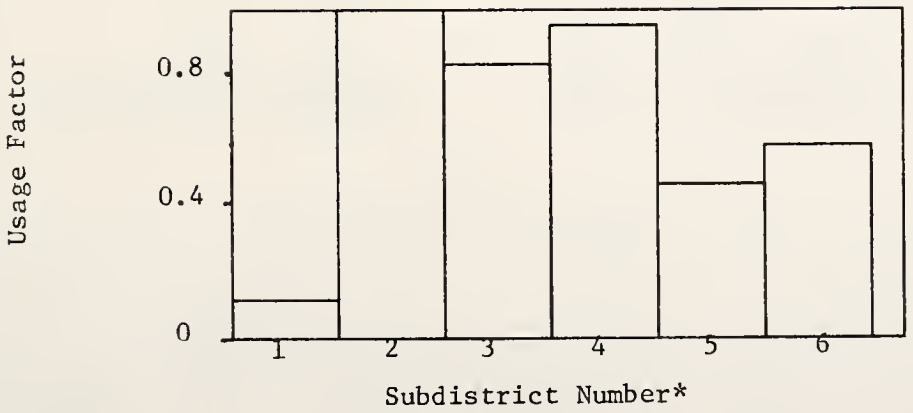


Figure 16. Usage Factors for Pickup Truck- Spot Litter Pickup Combination (by Subdistrict)

* Refer to figure 5 for subdistrict names and locations.

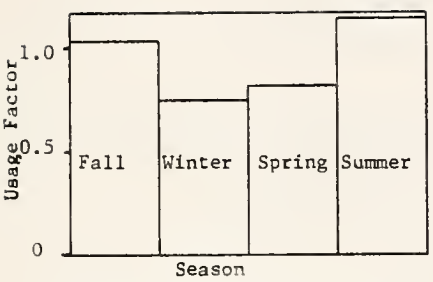


Figure 17. Usage Factor for Dump Truck - Shallow Patching Combination (by Season)

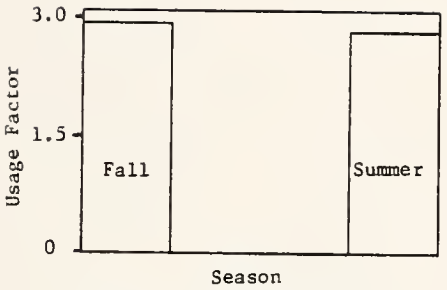


Figure 18. Usage Factors for Tractor Truck - Machine Mowing Combination (by Season)

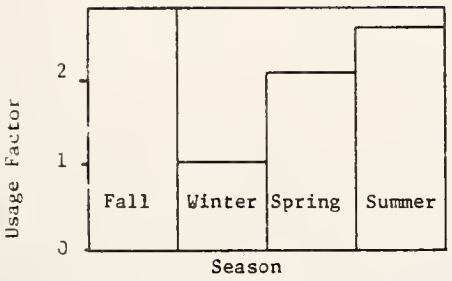


Figure 19. Usage Factors for Dump Truck - Clean and Reshape Ditches Combination (by Season)

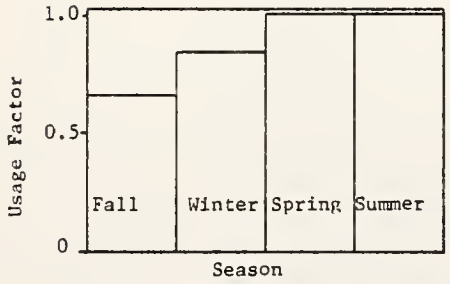


Figure 20. Usage Factors for Utility Truck - Sign Maintenance Combination (by Subdistrict)

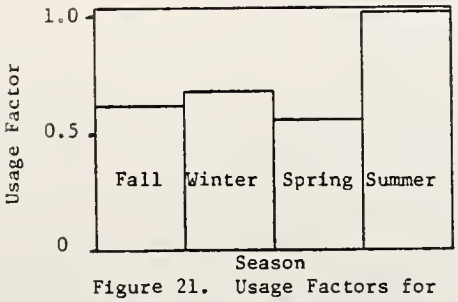


Figure 21. Usage Factors for Pickup Truck - Spot Litter Pickup Combination (by Season)

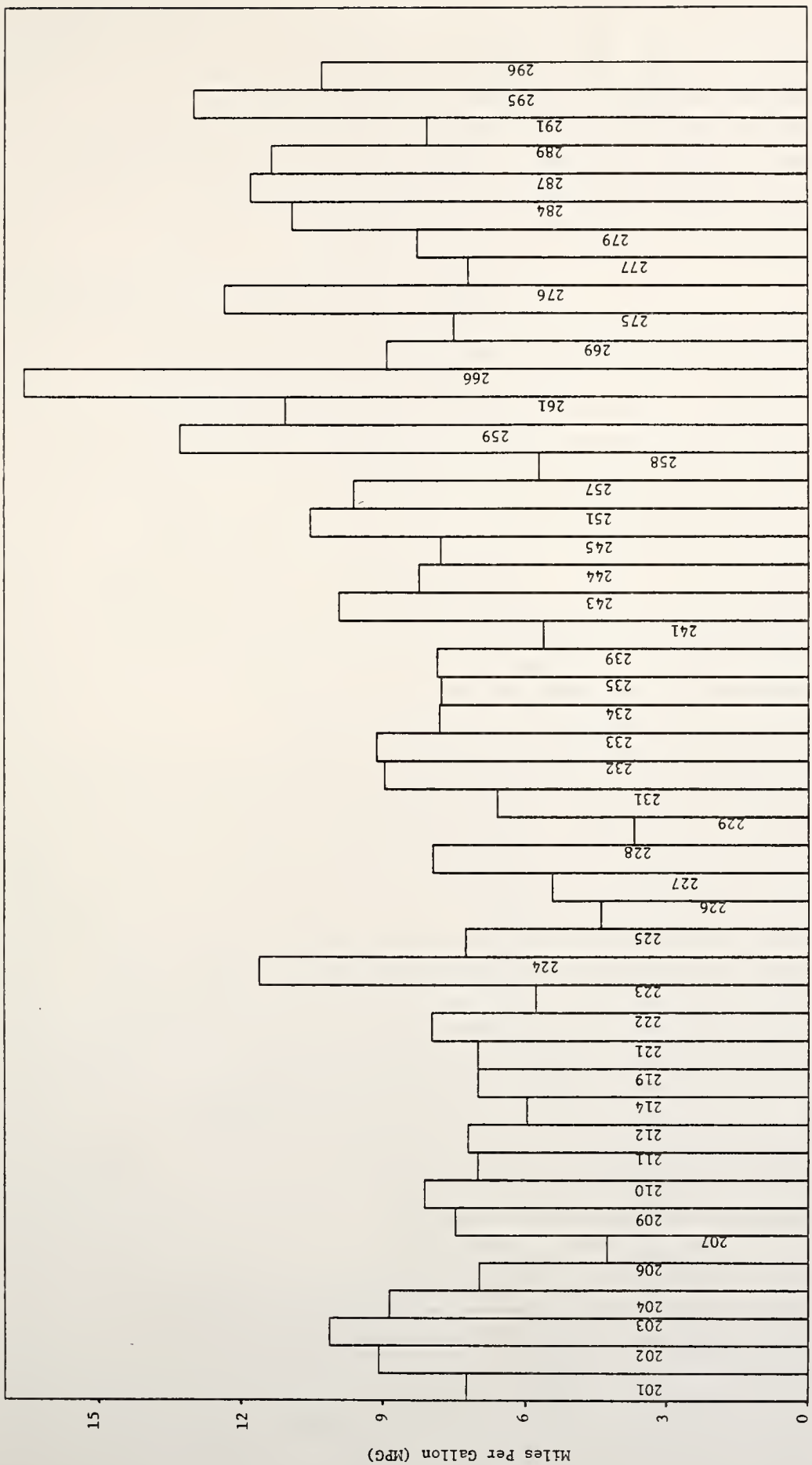


Figure 22. Fuel Consumption Rates (Miles Per Gallon) for a Pickup Truck.
* Refer to Table 1 for Activity Names.

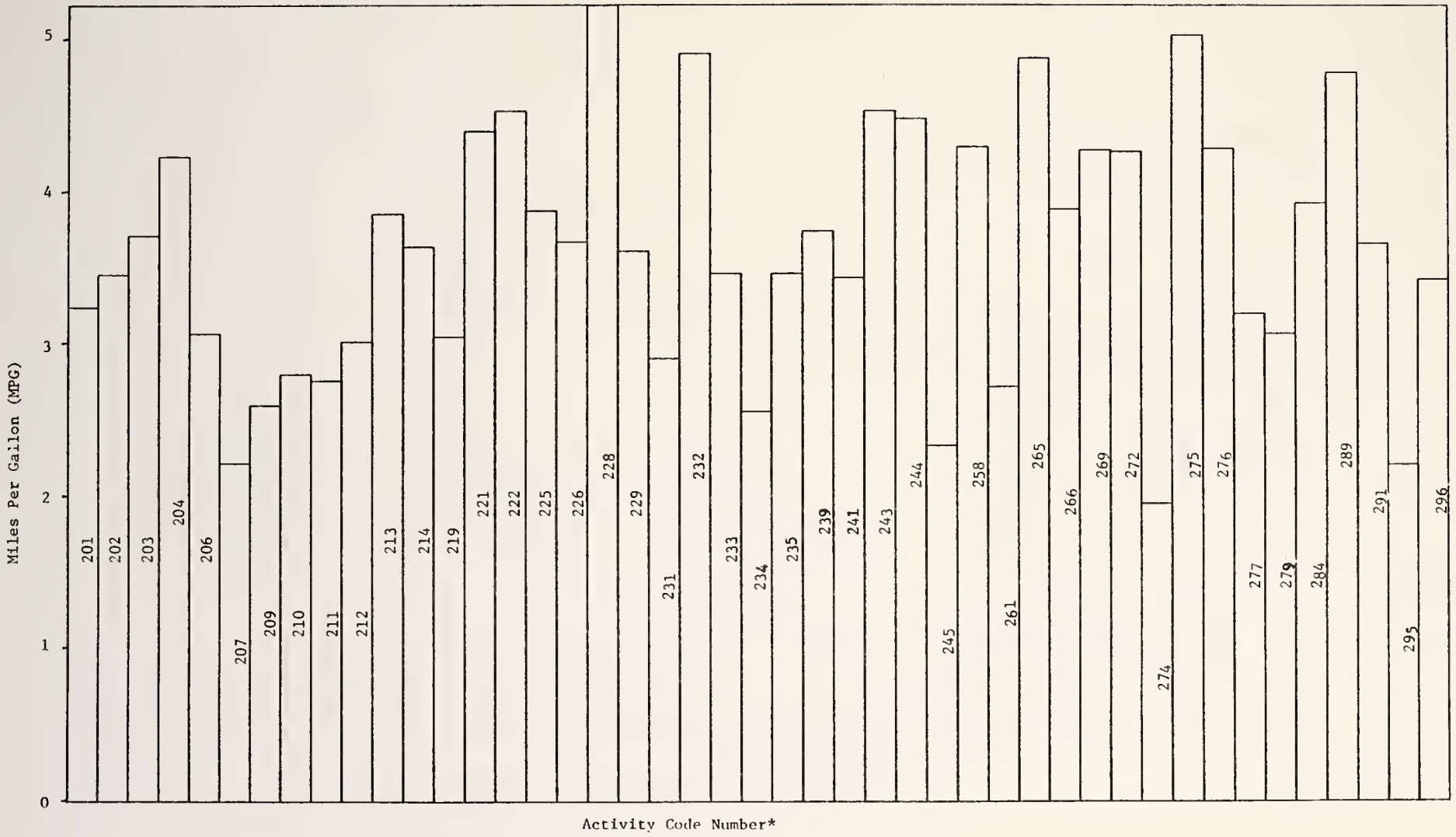


Figure 23. Fuel Consumption Rates (Miles Per Gallon) for a Dump Truck.

* Refer to Table 1 for Activity Names.

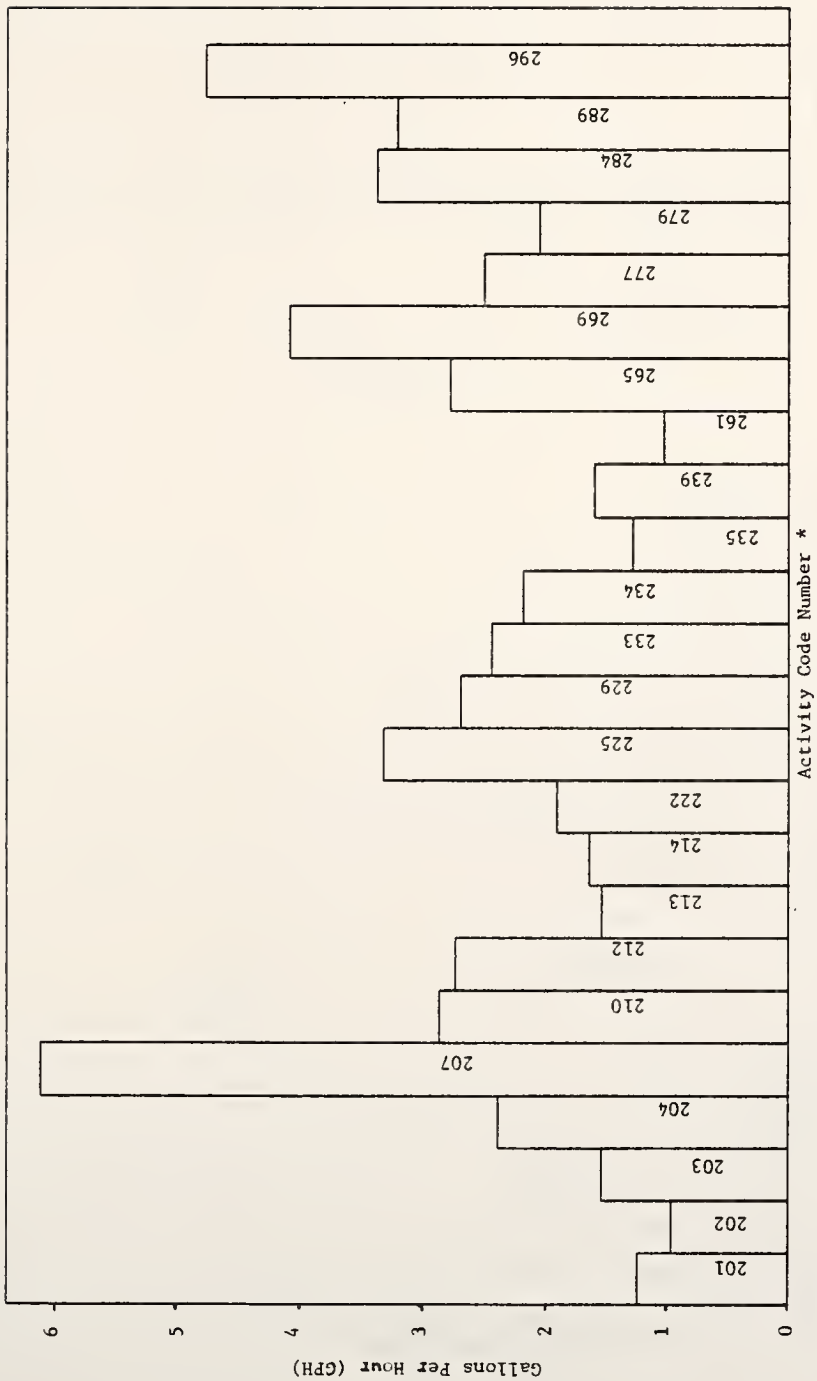


Figure 24. Fuel Consumption Rates (Gallons Per Hour) for a Loader.

*Refer to table 1 for activity names.

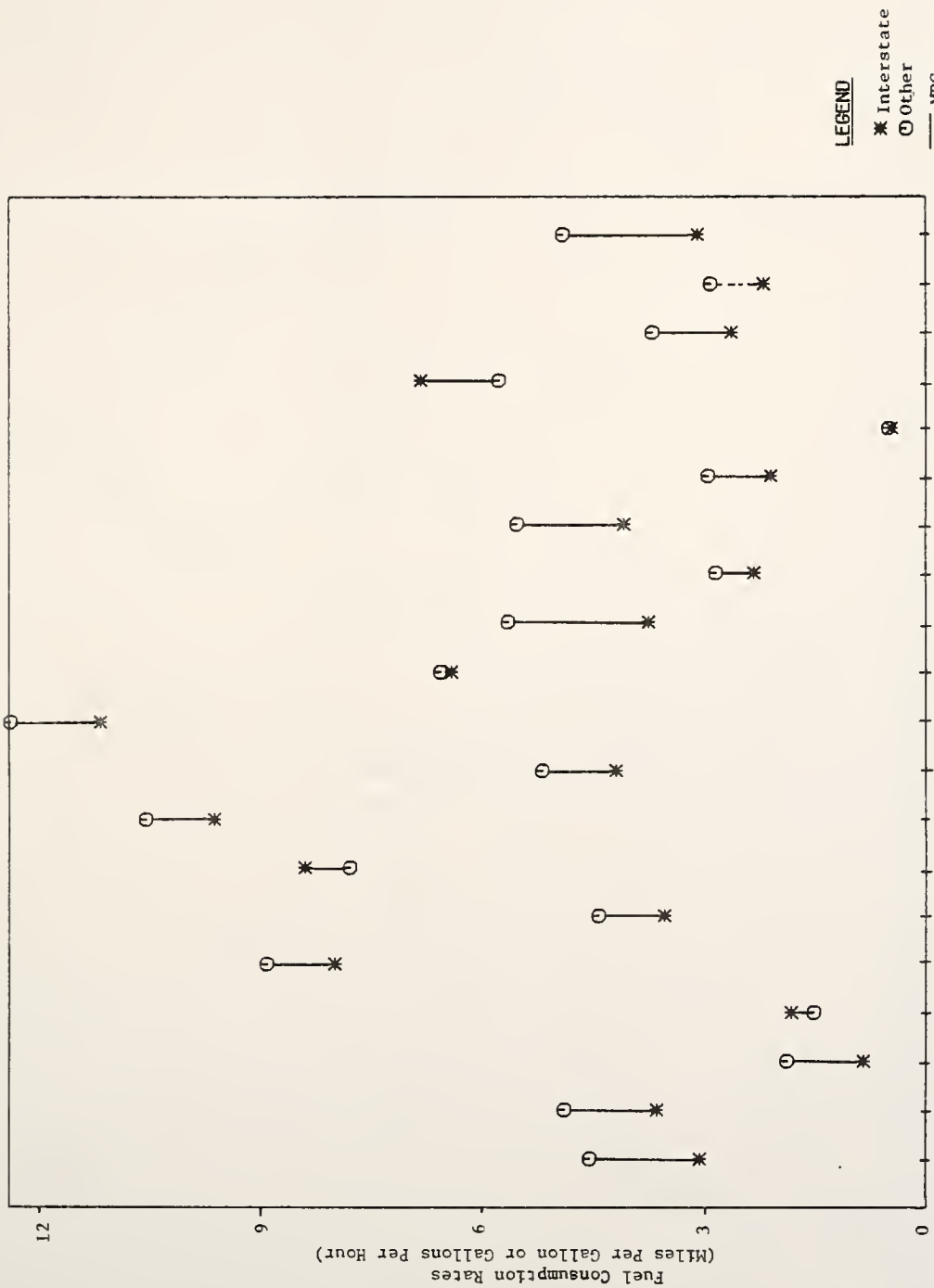


Figure 25. Test Results of Comparing Fuel Consumption Rates in Interstate and Other State Highway Systems.

* Refer to Table 13 for test description.

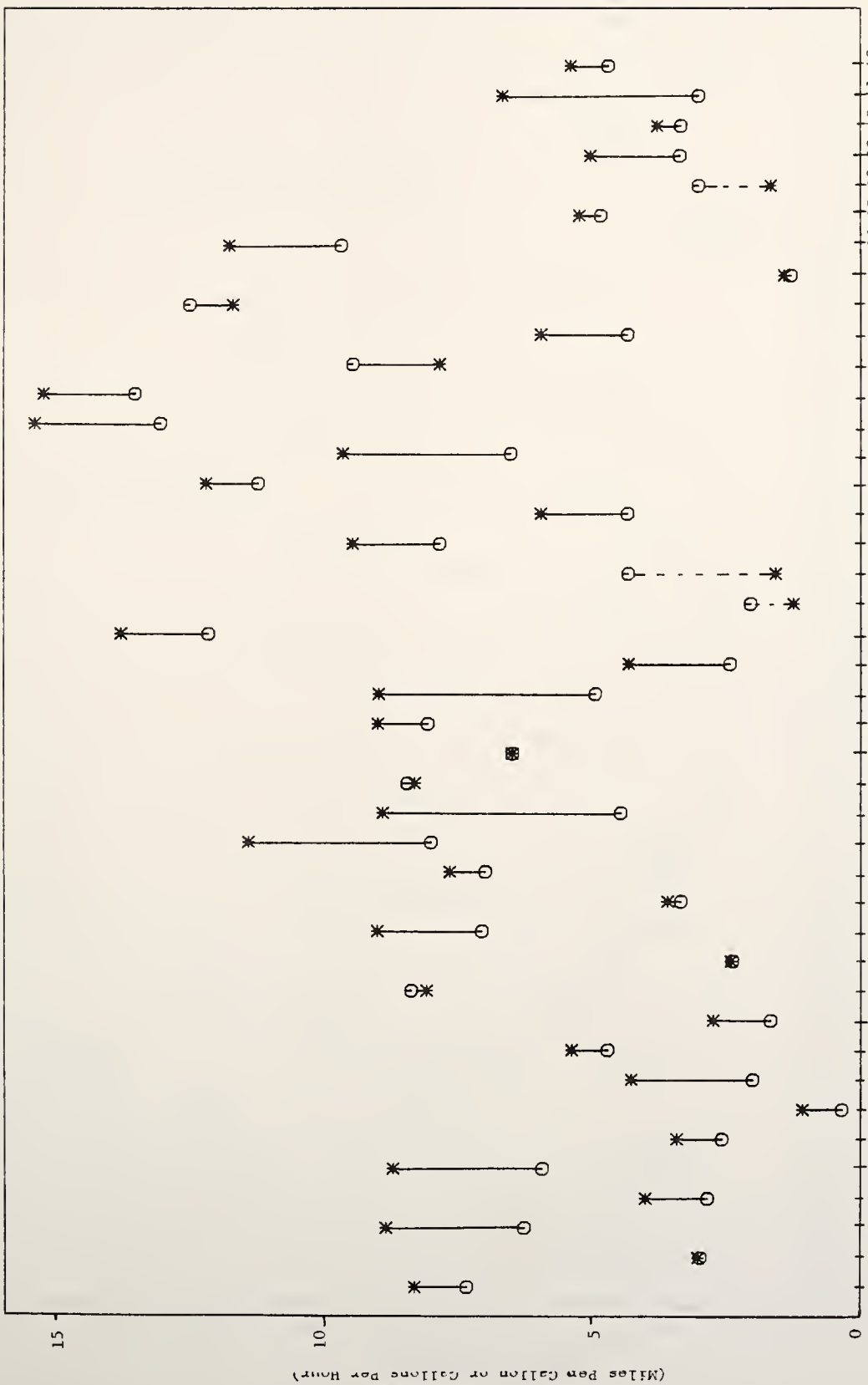


Figure 26. Test Results of Comparing Fuel Consumption Rates in Fall and Winter Seasons

* Refer to Table 14 for Test Description.

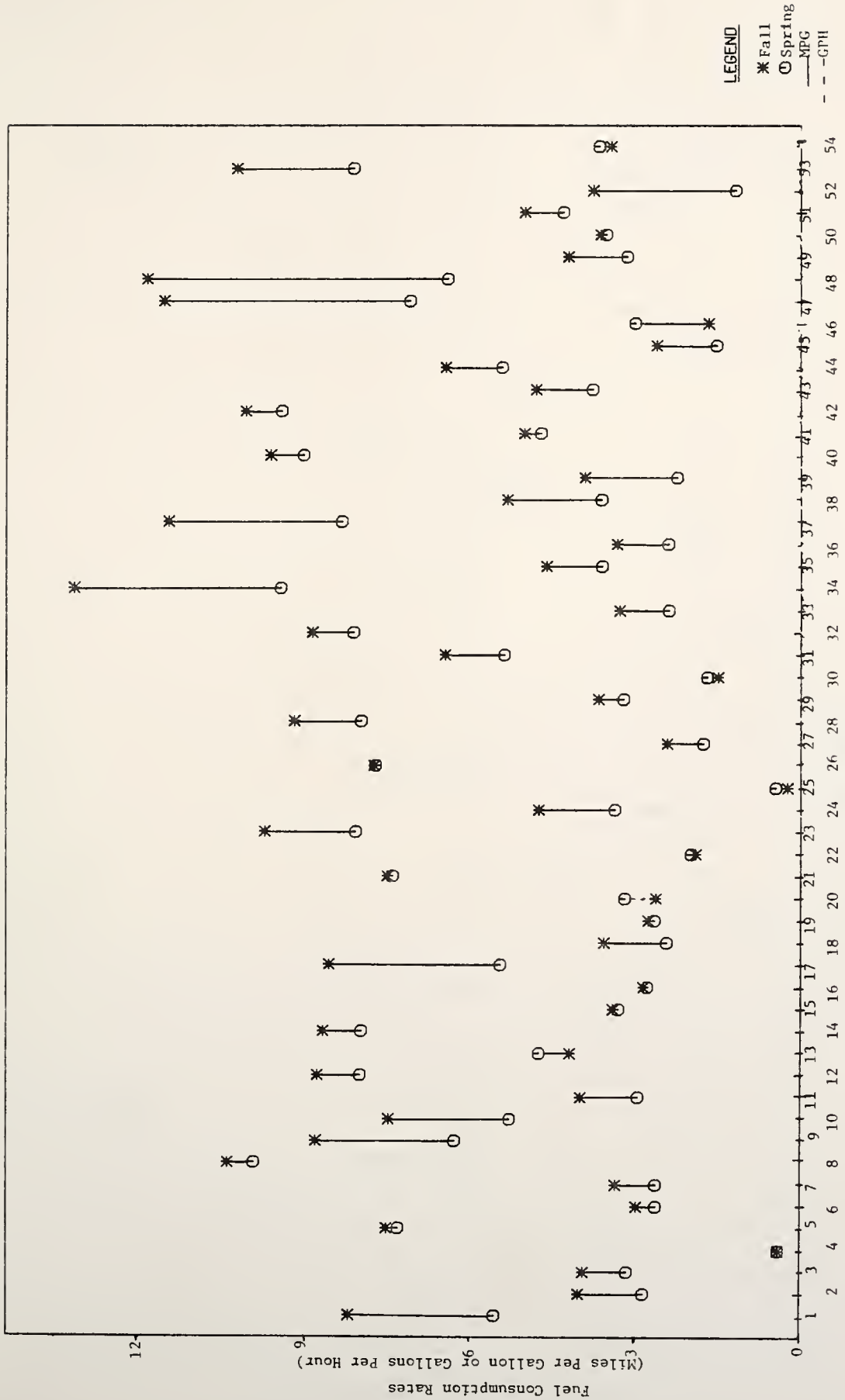


Figure 27. Test Results of Comparing Fuel Consumption Rates in Fall and Spring Seasons.
* Refer to Table 14 for Test Description.

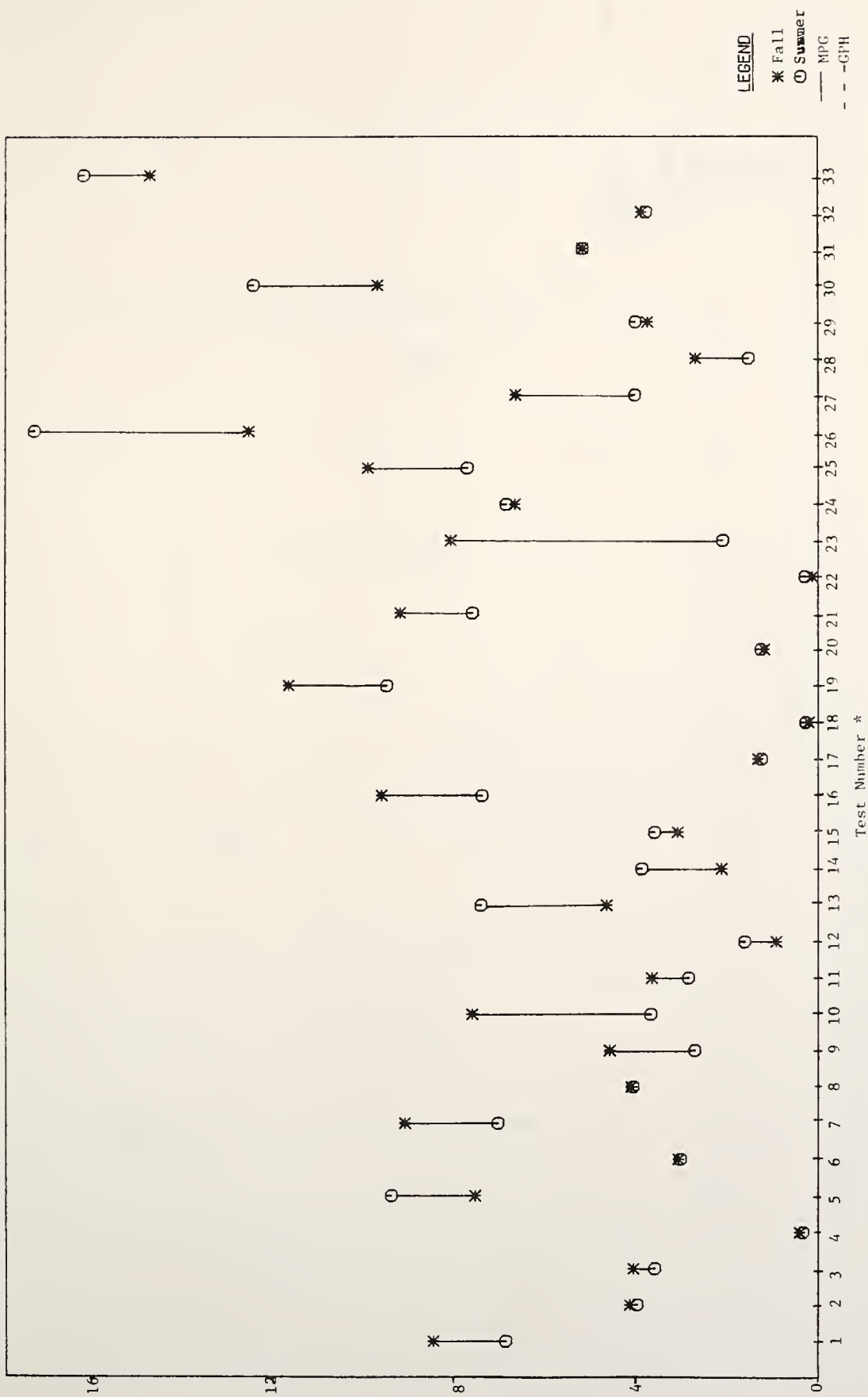


Figure 28. Test Results of Comparing Fuel Consumption Rates in Fall and Summer Seasons.

* Refer to Table 14 for Test Description.

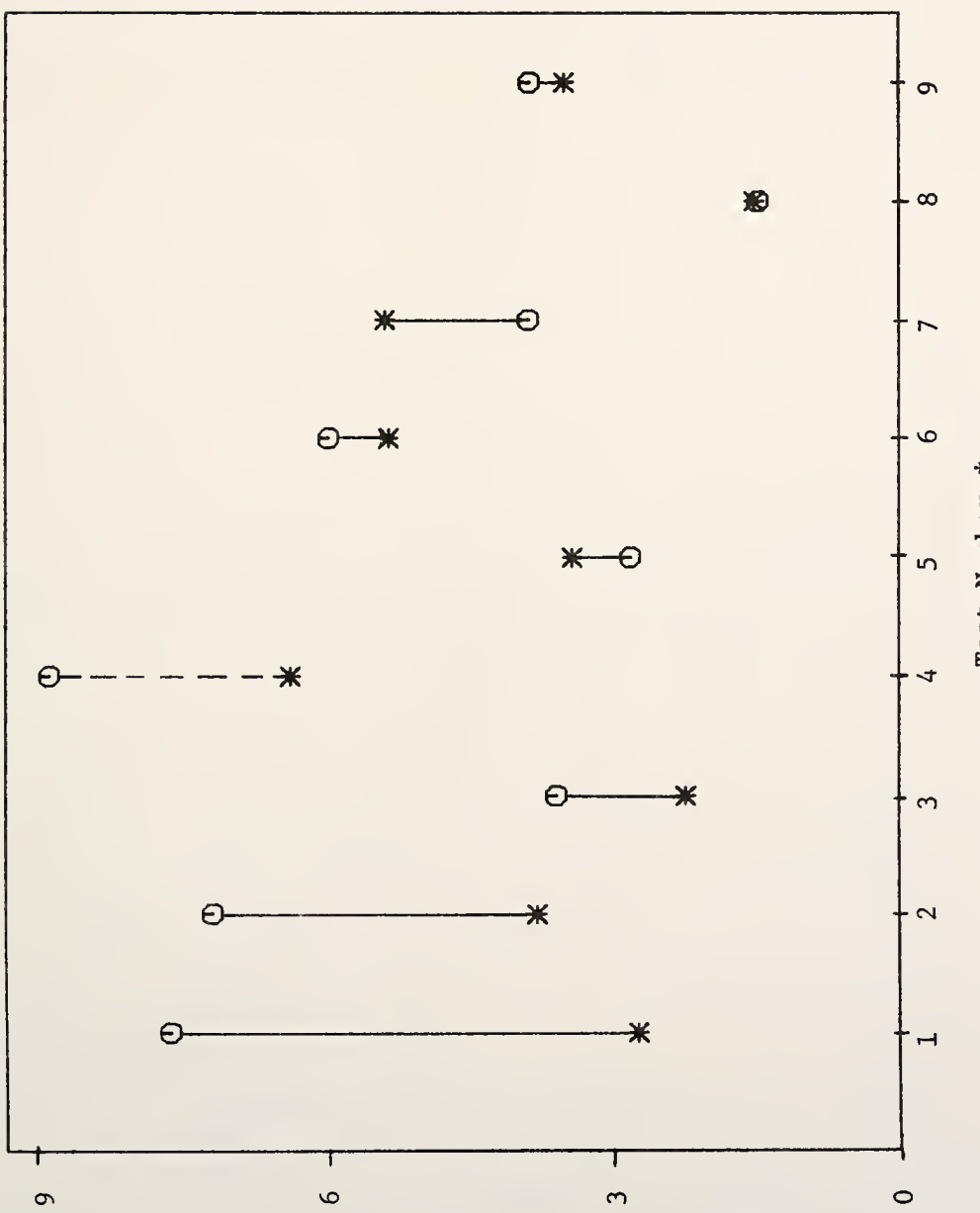


Figure 29. Test Results of Comparing Fuel Consumption Rates in Spring and Summer Seasons

* Refer to Table 14 for test description.

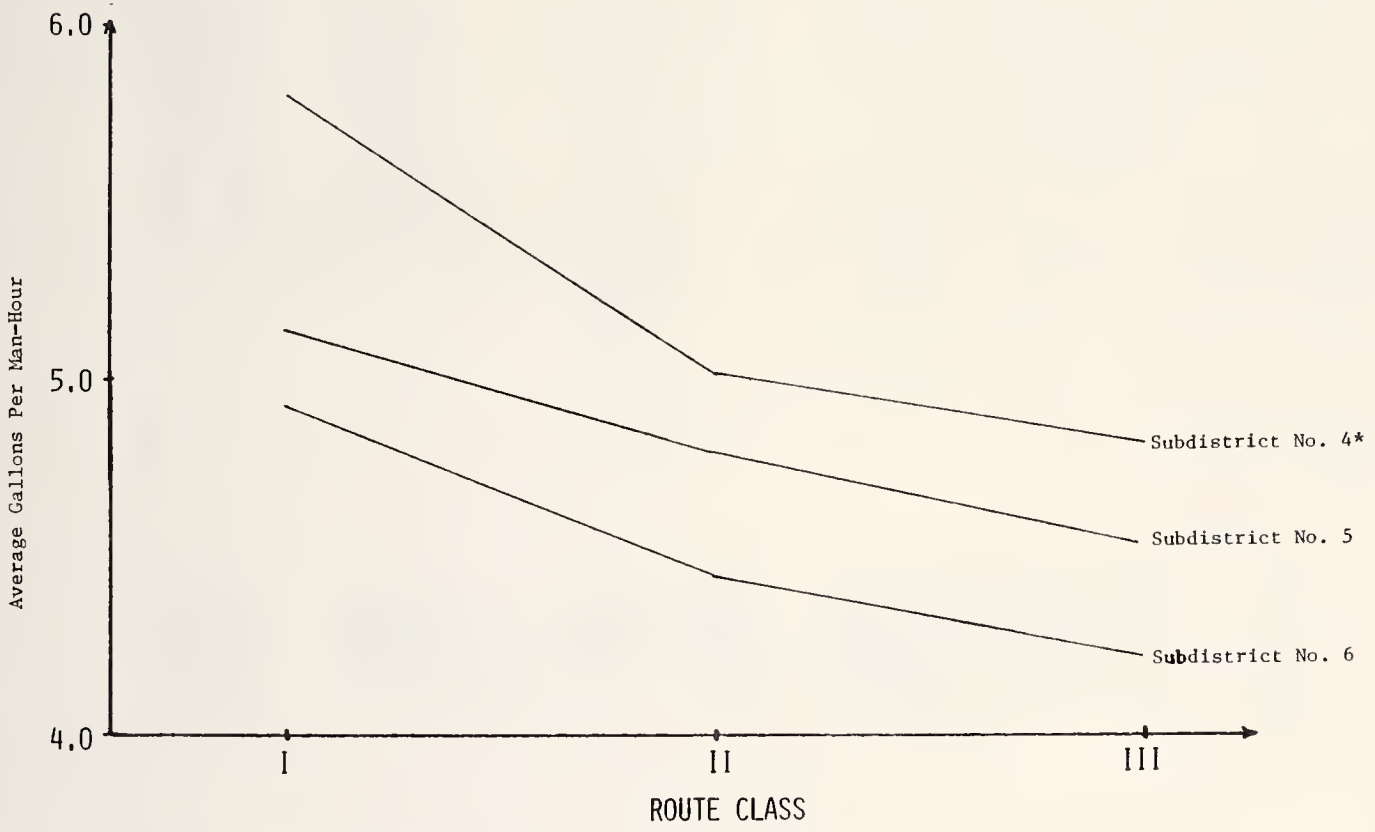


Figure 30. Average Fuel Consumption Rates for Snow and Ice Removal Activity.

* Refer to figure 5 for subdistrict names and locations.

Table 1. Routine Maintenance Activities Included in the Study

Code No.	Activity Name	Unit of Measure
	I. Roadway and Shoulder	
201	Shallow patching	Tons of mix
202	Deep patching	Tons of mix
203	Premix leveling	Tons of mix
204	Full width shoulder seal	Foot miles
205	Seal coating[1]	Lanes miles
206	Sealing longitudinal cracks and joints	Linear miles
207	Sealing cracks	Lane miles
209	Cutting relief joints	Linear feet
210	Spot repair of unpaved shoulders	Tons of aggregate
211	Blading shoulders	Shoulder miles
212	Clipping unpaved shoulders	Shoulder miles
213	Reconditioning unpaved shoulders	Shoulder miles
214	Joint and bump burning	Bumps removed
219	Others	Man-hours
	II. Roadside	
221	Machine mowing	Swath miles
222	Brush cutting	Man-hours
223	Herbicide treatment	Man-hours
224	Seeding and/or fertilizing	Man-hours
225	Topping, trimming or removal of long trees	Trees
226	Stump removal	Stumps
227	Spot mowing and hand trimming	Man-hours
228	Right-of-way fence repair	Linear feet
229	Others	Man-hours
	III. Drainage	
231	Clean and reshape ditches	Linear feet
232	Inspect minor drainage structures	Structures
233	Pipe replacement	Location
234	Motor patrol ditching	Ditch mile
235	Cleaning minor drainage structures	Structures
239	Others	Man-hours
	IV. Bridges	
241	Hand cleaning bridges	Decks cleaned
243	Bridge repair	Man-hours
244	Flushing bridges	Decks flushed
245	Patching bridge decks	Square feet
249	Others[1]	

Code No.	Activity Name	Unit of Measure
	V. Traffic Control	
251	Subdistrict sign maintenance	Man-hours
257	Paint pavement messages and special markings	Man-hours
258	Guardrail maintenance	Linear feet
259	Others	Man-hours
	VI. Winter and Emergency	
261	Emergency maintenance	Man-hours
263	Snow and ice removal*	Man-hours
265	Stockpiling winter materials	Man-hours
269	Others	Man-hours
	VII. Public Service	
271	Rest area and lift bridge attendant[1]	Man-hours
272	Roadside park, rest area, and weigh station maintenance	Man-hours
273	Work of Department of Natural Resources[1]	Man-hours
274	Work for state institutions	Man-hours
275	Full width litter pickup	R.O.W. Pass. miles
276	Spot litter pickup	Man-hours
277	Roadway cleaning	Man-hours
279	Others	Man-hours
	VIII. Others	
281	Equipment repair and maintenance[1]	Man-hours
283	Buildings and grounds maintenance[1]	Man-hours
284	Materials handling and storage	Man-hours
287	Detour maintenance	Man-hours
289	Other support activities	Man-hours
291	Special maintenance	Man-hours
295	Special maintenance	Man-hours
296	Special maintenance	Man-hours
112	Field maintenance supervision[2]	Man-hours
117	Training[2]	Man-hours
120	Standby time[2]	Man-hours
900	Leave[2]	Man-hours

* Snow and ice removal activity will be analyzed in special section at the end of this report.

[1] No data were received for these activities.

[2] No data for these activities (they are not recorded on crew day cards).

Table 2: Sample Sizes for Activity - Season Combinations

Activity No.[1]	Number of Observations				Activity No.	Number of Observations			
	Fall	Winter	Spring	Summer		Fall	Winter	Spring	Summer
201	55	46	185	56	245	4	2	0	2
202	12	0	6	7	249	NA	NA	NA	NA
203	5	0	0	3	251	90	45	38	12
204	4	0	0	0	257	6	0	0	2
205	NA[2]	NA	NA	NA	258	5	2	4	0
206	13	0	0	4	259	7	5	0	0
207	61	12	8	0	261	9	9	4	0
209	18	0	0	0	263	0	783	314	0
210	28	4	0	8	265	7	42	3	3
211	41	3	18	0	266	0	12	7	0
212	18	0	5	0	269	34	0	6	0
213	4	0	0	0	271	NA	NA	NA	NA
214	15	0	0	0	272	7	0	4	0
219	5	0	0	0	273	NA	NA	NA	NA
221	39	0	0	126	274	4	0	0	0
222	17	10	11	5	275	15	3	18	8
223	9	0	0	0	276	77	15	30	8
224	3	0	0	0	277	17	0	11	0
225	8	5	4	0	279	5	0	17	0
226	6	0	0	0	281	NA	NA	NA	NA
227	8	0	2	4	283	NA	NA	NA	NA
228	6	3	4	0	284	25	8	6	8
229	4	0	7	0	287	17	0	4	0
231	36	0	10	12	289	63	12	21	9
232	12	9	3	4	291	7	0	0	0
233	16	0	4	0	295	2	0	0	0
234	11	0	0	0	296	19	0	0	0
235	18	3	5	0	112	NA	NA	NA	NA
239	23	4	7	4	117	NA	NA	NA	NA
241	0	0	34	0	120	NA	NA	NA	NA
243	10	0	3	0	900	NA	NA	NA	NA
244	0	0	8	0					
					TOTAL	925	1067	811	385

[1] Refer to Table 1 for activity names.

[2] Not available (no crew cards were received).

Table 3. List of Equipment Used in Routine Maintenance Activities

Code No.	Equipment Type	Code No.	Equipment Type	Code No.	Equipment Type
1	Pickup truck	36	Chain saw	71	Ave all
2	Pickup crew cab	37	Concrete saw	72	Sewer jet
3	Aerial Basket truck	38	Pavement Cutter	73	Crane
4	Flatbed truck	39	Hydro-seeder	74	Stake truck
5	Water truck	40	Weed sprayer	75	Generator
6	Bucket truck	41	Paint machine	76	Port Line marker
7	Distributer	42	Tractor truck	77	Van
8	Utility truck	43	Tractor mower	78	Sewer vector
9	Dump truck	44	Compressor	79	Vermeer trailer
10	Do-all truck	45	Mixer		
11	Catch basin cleaner	46	Squeegee Cart		
12	Compactor	47	Flashing arrow board		
13	Tar kettle	48	Porta patcher		
14	Premix storage trailer	49	Jeep		
15	Burner unit	50	Lowboy trailer		
16	Paver	51	Trailer		
17	Widener	52	Pavement Cutter		
18	Jack hammer	53	Chemical spreader		
19	Portable roller	54	Maintainer		
20	Roller	55	Back blade		
21	Street sweeper	56	Berm drag		
22	Broom	57	Undeck body		
23	Backhoe	58	Broom tractor		
24	Excavator	59	Weed eater		
25	Grader	60	Rotor tiller		
26	Loader	61	Rack truck		
27	Snow blow	62	Tilt cab		
28	Chip spreader	63	Pole truck		
29	Salt spreader	64	Gradall		
30	Underbody scrapper	65	Pavement breaker		
31	Brush chipper	66	Semi trailer		
32	Stump cutter	67	Dozzer		
33	Auger/driver	68	W hocker		
34	Lawn Mower	69	Crawler		
35	Hand mower	70	Vermeer cutter		

Table 4. List of Materials Used in Maintenance Activities

Code No.	Material Name	Unit of Measure	Unit Cost (1982 $)
1	Aggregate or backfill	ton	4.10
2	Seal cover aggregate	ton	3.00
3	Bituminous material	gallon	0.78
4	Bituminous mixture	ton	25.50
5	Salvage bituminous mixture	ton	25.50
6	Preformed joint fill	linear foot	3.10
7	Herbicides	gallon	22.00
8	Dry herbicides	pound	1.14
9	Grass seed	pound	0.85
10	Fertilizer	pound	0.07
11	Fence	linear foot	1.16
12	Fence posts	each	13.20
13	Culvert pipe	linear foot	14.00
14	Cement	bag	4.50
15	Fast setting concrete	bag	8.00
16	Delineators	each	0.29
17	Delineator posts	each	3.00
18	Underdrain pipe	linear foot	14.00
19	Rip Rap	ton	4.32
20	Ready-mix concrete	cubic yard	39.35
21	Sacrete	pound	0.51
22	Signs	each	18.00
23	Sign posts	each	7.80
24	Epoxy sealer	gallon	8.50
25	Signal lamps	each	0.50
26	Signal posts	each	475.00
27	Glass beads	pound	0.21
28	Green lite powder	pound	1.32
29	White slow dry	gallon	3.74
30	Guardrail sections	linear foot	6.67
31	Abrasives	ton	2.40
32	Yellow slow dry traff	gallon	4.30
33	Primer	gallon	10.00
34	Yellow quick dry traff	gallon	4.52
35	Solvent	gallon	1.65
36	Silica sand	ton	65.00
37	Lumber	board foot	3.20
38	Salt	ton	28.00
39	Calcium chloride	pound	0.07

Table 5. Labor Categories Used in Maintenance Activities

Labor Category Number		Average Hourly Wage[1] ($)
1	Maintenance worker (IV)	5.67
2	Maintenance worker (III)	6.52
3	Maintenance worker (II)	7.21
4	Rest park attendant	5.43
5	Highway maintenance supervisor	7.59
6	Traffic signal technician	6.50

[1]1982 rates (Fringe benefits are not included).

Table 6: Cost Calculation Example (for Shallow Patching Activity).

Resource	i	Element	j	f_{ij}	R_{ij}	C_{ij}	Total Cost
Labor	1	Maintenance Worker IV	1	5.0	2.23 m.hr/Prod. Unit	$5.67 / m.hr.	$77.77 Labor Cost per Production Unit.
	1	" " III	2	1.0	2.23 m.hr/Prod. Unit	$6.52 / m.hr.	
Materials	2	Aggreg. or backfill	1	0.02	1.00 tons/Prod. Unit	4.10 / ton	$27.30 Material Cost per Production Unit.
	2	Seal Cover Aggreg.	2	0.02	0.30 tons/ " "	3.00 / ton	
	2	Bit. Material	3	0.30	7.77 gallons/ " "	0.78 / gallon	
	2	Bit. Mix	4	0.50	1.00 tons/ " "	25.50 / ton	
	2	Salvage Bit. Mix	5	0.50	1.00 tons/ " "	25.50 / ton	
Equipment	3	Pickup Truck	1	0.10	3.66 gallons/ " "	1.05 / gallon	$9.32 Fuel Cost per Production Unit.
	3	Pickup Crew Cab	2	1.10	2.69 " " "	"	
	3	Flatbed Truck	3	0.06	3.27 " " "	"	
	3	Distributer	4	0.02	2.53 " " "	"	
	3	Utility Truck	5	0.01	4.22 " " "	"	
	3	Dump Truck	6	0.91	4.78 " " "	"	
	3	Do-all Truck	7	0.12	3.71 " " "	"	
	3	Compactor	8	0.10	0.19 " " "	"	
	3	Tar Kettle	9	0.06	0.00 " " "	"	
	3	Premix Storage Trailer	10	0.49	0.00 " " "	"	
	3	Roller	11	0.05	0.60 " " "	"	
	3	Loader	12	0.03	1.66 " " "	"	
	3	Air Compressor	13	0.01	2.17 " " "	"	
	3	Flashing Arrow Board	14	0.18	1.14 " " "	"	
	3	Porta Patcher	15	0.09	0.00 " " "	"	
	3	Stake Truck	16	0.01	7.14 " " "	"	

$114.39 Total Cost per Production Unit.

Table 7: Summary of Resource Costs for Different Activities.

Activity[1] No.	Total[2] Production (1982)	Average Fuel Gallons Per Production Unit	Average[3] Fuel Cost Per Production Unit	Average[4] Materials Cost Per Production Unit	Average Labor Cost Per Production Unit	Total Fuel Cost ($1982)	Total Material Cost ($1982)	Total Labor Cost ($1982)	Total Costs ($1982)	Fuel Cost as Percent of Material Cost	Fuel Cost as Percent of Total Cost
201	33812.	8.88	9.32	27.30	77.77	315263.	923068.	2629559	3867890	25.46	8.15
202	6602.	8.46	8.88	25.98	31.77	58646	171520.	209746	439911	25.48	13.33
203	9971	5.05	5.30	26.84	13.93	52871.	267622.	138896	459389.	16.50	11.51
204	5371.	7.77	8.16	77.56	19.65	43819	416575.	105540	565934	9.52	7.74
205	836	85.47	89.74	1435.41	158.32	75026	1200003.	132356	1407384	5.88	5.33
206	2849.	7.86	8.25	56.00	49.72	23513	159544.	141652	324709.	12.84	7.24
207	6625.	23.25	24.41	114.64	166.85	161733	759490.	1105381	2026604	17.56	7.98
209	28855.	.52	.55	2.14	2.67	15755	61750.	77043	154547	20.33	10.19
210	54945.	2.15	2.26	4.10	7.55	124038.	225274.	414835.	764148.	35.51	16.23
211	14986	2.67	2.80	0	12.49	42013.	0	187175	229188.	100.00	18.33
212	2224	52.87	55.51	0	147.00	123462.	0	326928	450390.	100.00	27.41
213	198	60.41	63.43	305.86	162.45	12559.	60560.	32165	105285.	17.18	11.93
214	7666	2.13	2.24	1.09	25.15	17145.	8356.	192800	218301	67.23	7.85
219	26161	.53	.56	3.10	5.85	14559.	81099	153042.	248700.	15.22	5.85
221	109807.	1.86	1.95	0	6.65	214453.	0	730217.	944670.	100.00	22.70
222	49506	.74	.78	0	5.99	38466.	0	296541.	335007	100.00	11.48
223	16032.	84	.88	15.65	5.95	14140.	250901.	95390.	360431	5.34	3.92
224	948	.22	.23	7.03	5.95	219.	6664.	5641.	12524	3.18	1.75
225	1742.	20.66	21.69	0	106.48	37789.	0	185488	223277	100.00	16.92
226	716	5.05	5.30	0	14.08	3797.	0	10081.	13878.	100.00	27.36
227	27130	.76	80	0	5.95	21650	0	161423	183073.	100.00	11.83
228	52594	16	.17	1.24	1.13	8836.	65217	59431	133484	11.93	6.62
229	13655	1.41	1.48	0	5.93	20216.	0	80974	101190	100.00	19.98
231	1693142.	23	24	03	.58	408894.	50794	982022	1441710	88.95	28.36
232	48924	26	27	0	3.72	13356.	0	181997	195354	100.00	6.84
233	509	62.10	65.20	749.41	365.81	33189	381450	186197	600836	8.00	5.52
234	382	78.22	82.13	0	349.50	31374	0	133509	164883	100.00	19.03

235	19752	3.87	4.06	0	24.05	80262.	0	475036.	555298.	100.00	14.45
239	69151	82	86	3.82	5.88	59539	264157	406608	730304	18.39	8.15
241	4571.	5.42	5.69	0	46.60	26014.	0	213009.	239022.	100.00	10.88
243	10063.	.59	62	2.10	6.10	6234.	21132.	61384	88751	22.78	7.02
244	3315.	2.20	2.31	0	20.50	7658.	0	67958	75615	100.00	10.13
245	21722.	96	1.01	49	5.43	21896.	10644	117950	150490	67.29	14.55
249	3673.	.59	.62	1.09	5.85	2275	4004	21487	27766	36.24	8.19
251	106850.	1.04	1.09	5.10	6.20	116680	544935	662470	1324085	17.64	8.81
257	21364.	.75	.79	2.82	6.00	16824	60246	128184	205255	21.83	8.20
258	32738	.88	92	6.20	7.13	30250	202976	233422	466647	12.97	6.48
259	7064	1.15	1.21	0	5.92	8530	0	41819	50349	100.00	16.94
261	20441	1.74	1.83	1.00	6.10	37346	20441	124690	182477	64.63	20.47
263	431926.	5.00	5.25	22.46	6.50	2267611.	9701058	2807519	14776188	18.95	15.35
265	38400	1.91	2.01	0	5.76	77011	0	221184.	298195	100.00	25.83
266	20010	3.41	3.58	0	5.67	71646.	0	113457.	185103	100.00	38.71
269	134905	.77	.81	.23	5.84	109071.	31028	787845	927944	77.85	11.75
271	170513	93	98	0	5.40	166506.	0	920770	1087276	100.00	15.31
272	18674	.93	.98	0	5.67	18235.	0	105882.	124117.	100.00	14.69
273	3922	.62	.65	4.88	6.00	2553.	19139	23532.	45225	11.77	5.65
274	2245.	.62	.65	2.17	5.89	1461.	4872.	13223.	19556	23.08	7.47
275	8345.	2.47	2.59	0	17.95	21643	0	149793	171436.	100.00	12.62
276	87753	.93	.98	0	5.67	85691.	0	497560	583250.	100.00	14.69
277	32213	.76	.80	0	6.17	25706.	0	198754	224460	100.00	11.45
279	15088	1.89	1.98	0	5.67	29942.	0	85549	115491	100.00	25.93
281	114804.	0	0	0	6.00	0	0	688824	688824	0	0
283	151541.	1.56	1.64	0	6.00	248224	0	909246	1157470	100.00	21.45
284	38962	3.55	3.73	0	5.95	145231	0	231824	377055	100.00	38.52
287	20244	1.03	1.08	0	6.10	21894	0	123488	145382	100.00	15.06
289	76575	2.72	2.86	0	6.10	218698	0	467107	685806.	100.00	31.89
291	6700	1.77	1.86	30.80	6.30	12452	206360	42210	261022	5.69	4.77

295	668	60	63	9 56	6 30	421	6386	4208	11015	6 18	3 82
296	23974	1 56	1 64	14 90	6 30	39269	357213	151036	547518	9 90	7 17
112	309313	0	0	0	8 00	0	0	2474504	2474504.	0	0
117	71345	0	0	0	6 00	0	0	428070	428070	0	0
120	29345	0	0	0	6 00	0	0	176070	176070	0	0
900	389467	0	0	0	5 50	0	0	2142069	2142069	0	0
TOTAL						5903555	16544476.	25273771.	47721802	26 30	12 37

1. Refer to Table 1 for activity names.
2. Source: Reference No. 14.
3. Based on $1.05 per gallon.
4. Materials other than fuel.

Table 8: Fuel Intensive Activities and Associated Costs

Activity[1] No.	Name	Estimated Fuel cost ($1982)
263	Snow and Ice Removal[2]	2,267,611
231	Clean and Repair Ditches	408,894
201	Shallow Patching	315,263
289	Other Support Activities	218,698
221	Machine Mowing	214,453
207	Crack sealing	161,733
284	Material Handling and Storage	145,231
210	Spot Repair of Unpaved Shoulders	124,038
212	Chipping Unpaved Shoulders	123,462
251	Subdistrict Sign Maintenance	116,680

1. Refer to Table 1 for Activity Names.

2. Details are given in a seperate section at the end of this report.

Table 9: List of Routine Maintenance Activities in Work Control Categories.

WORK CONTROL CATEGORY	LIST OF ACTIVITIES [1]
OVERHEAD	271 272 273 274 279 281 283 284 289 112 117 120 900
UNLIMITED	201 202 210 221 221 223 225 226 227 235 243 245 251 257 258 261 263 265 266 269 276 287
LIMITED	204 205 206 207 209 211 212 224 231 232 233 234 241 244
VARIABLE	203 213 214 219 222 228 229 239 249 259 275 277 291 295 296

1. Refer to Table 1 for activity names.

Table 10. Equipment Usage Factors

Activity Number[1]	Usage Factors[2] by Equipment Code Number[3]															
201:	1	2	4	7	8	9	10	12	13	14	20	26	44	47	48	74
	0.10	1.10	0.06	0.02	0.01	0.91	0.12	0.10	0.06	0.49	0.05	0.03	0.01	0.18	0.09	0.01
202:	1	2	8	9	10	12	13	14	20	23	26	42	44	47	48	50
	0.05	0.06	0.10	1.90	0.03	0.60	0.10	0.10	0.50	0.50	0.50	0.20	0.40	0.20	0.10	0.20
203:	1	2	7	9	10	13	14	16	20	25	26	42	47	50	51	
	0.15	1.14	0.29	2.00	0.29	0.29	0.29	0.29	0.71	0.14	0.29	0.14	0.29	0.14	0.14	
204[4]:	1	2	7	9	13	26										
	1.00	1.00	1.00	9.00	2.00	1.00										
206:	1	2	4	7	9	10	13	44	47							
	1.64	0.07	0.14	0.35	1.64	0.21	0.64	0.42	0.21							
207:	1	2	7	9	10	13	26	42	44	47						
	0.53	1.13	0.34	1.77	0.57	0.75	0.03	0.04	0.40	0.21						
209:	1	2	9	10	14	47	50	51	52							
	0.40	0.80	1.00	0.20	0.30	0.20	0.30	0.10	1.00							
210:	1	2	9	10	12	14	20	25	26	27	47	53				
	0.75	0.36	0.50	1.33	0.03	0.03	0.03	0.03	0.06	0.42	0.03	0.03				
211:	1	2	9	10	20	22	25	27	30	42	47	54	55	56	57	
	0.52	0.25	0.62	0.10	0.10	0.07	0.53	0.38	0.02	0.73	0.02	0.18	0.13	0.10	0.02	
212:	1	2	9	22	25	26	42	50	58							
	0.85	0.60	3.35	0.45	1.00	0.55	0.05	0.05	0.45							

Activity Number[1]	Usage Factors[2] by Equipment Code Number[3]										
213:	2	9	10	26							
	1.00	3.67	0.34	0.34							
214:	1	2	9	10	13	15	25	26	47	54	
	0.93	0.60	0.40	0.20	0.07	0.47	0.47	0.13	0.40	0.13	
219:	1	2	9	10	13	37					
	0.80	0.20	0.40	0.40	0.20	0.40					
221:	1	2	9	10	26	34	42	59			
	0.12	0.81	0.07	0.01	0.01	2.80	2.80	0.30			
222:	1	2	4	6	9	23	26	31	36		
	0.21	0.83	0.05	0.02	0.81	0.02	0.02	0.24	1.05		
223:	1	2	40								
	0.60	0.40	0.80								
2244[4]:	1	40	60								
	1.00	1.00	1.00								
225:	1	2	3	4	9	10	26	31	32	36	61
	0.25	0.83	0.33	0.08	1.17	0.08	0.33	0.17	0.08	1.75	0.08
226:	1	2	4	9	32	62	63				
	0.20	0.20	0.20	0.60	1.00	0.20	0.20				
227:	1	2	34	35	36	42	59				
	0.36	0.64	0.57	0.07	0.07	0.5	0.57				
228:	1	2	9	49	62						
	0.86	0.14	0.14	0.14	0.14						
229:	1	2	9	25	26						
	0.11	0.55	1.56	0.11	0.67						

Activity Number[1]	Usage Factors[2] by Equipment Code Number[3]																
231:	1	2	9	10	23	24	25	47	64	77							
	0.51	0.86	2.56	0.02	0.04	0.96	0.02	0.08	0.04	0.02							
232:	1	2	9	10													
	0.85	0.08	0.04	0.04													
233:	1	2	9	10	12	20	23	24	26	42	44	51	65	66	67	68	70
	0.67	1.11	2.83	0.06	0.39	0.06	0.83	0.39	0.33	0.06	0.06	0.11	0.06	0.06	0.11	0.11	0.06
234:	1	2	9	22	25	26	47	58									
	0.81	0.91	2.73	0.27	1.10	1.00	0.36	0.54									
235:	1	2	9	10	11	23	26	45	71	72							
	0.74	0.35	0.17	0.04	0.43	0.04	0.04	0.04	0.08	0.04							
239:	1	2	8	9	12	23	25	26	42	44	51	64	70	73			
	0.61	0.26	0.05	1.18	0.03	0.47	0.03	0.10	0.03	0.11	0.26	0.03	0.03	0.03			
241:	1	2	4	9	44												
	0.74	0.50	0.08	0.24	0.66												
243:	1	2	8	9	13	23	44	45	74	75							
	1.40	0.67	0.07	0.33	0.20	0.07	0.27	0.13	0.27	0.27							
244:	1	2	5	9	40												
	0.67	0.33	0.33	0.56	0.67												
245:	1	2	9	10	37	44	45	47	48	65							
	0.60	1.80	2.20	0.20	0.20	0.80	0.40	0.60	0.20	0.60							
251:	1	2	8														
	0.18	0.03	0.79														
257:	1	2	8	44	51	76											
	0.86	0.14	0.86	0.29	0.29	0.86											

Activity Number[1]	Usage Factors[2] by Equipment Code Number[3]											
258:	1	2	9									
	1.00	0.67	0.33									
259:	1	8										
	0.12	0.88										
261:	1	2	8	9	10	21	26	27	36	44	53	74
	0.88	0.08	0.08	0.35	0.08	0.04	0.04	0.04	0.15	0.04	0.04	0.04
265:	4	9	10	23	26	42	53	77				
	0.02	0.37	0.17	0.02	1.11	0.02	0.02	0.02				
266:	1	2	9	10	27							
	0.15	0.35	0.45	0.15	0.05							
269:	1	2	9	10	26	44	53	74				
	0.07	0.44	0.63	0.17	0.07	0.29	0.10	0.05				
272:	2	4	9	25								
	0.75	0.25	0.75	0.25								
274:	2	9	10	13								
	1.33	1.00	1.00	1.00								
275:	1	2	9	53								
	0.27	0.34	0.39	0.02								
276:	1	2	9	10	53							
	0.62	0.20	0.21	0.01	0.01							
277:	1	2	4	9	21	22	23	26	42	44	50	77
	0.40	0.57	0.07	0.43	0.10	0.20	0.10	0.10	0.17	0.20	0.07	0.03
279:	1	2	9	26	28	31	47					
	0.15	0.45	1.20	0.05	0.05	0.35	0.05					

Activity Number[1]	Usage Factors[2] by Equipment Code Number[3]																	
284:	1	2	7	9	10	13	26	50	51									
	0.09	0.02	0.42	1.23	0.14	0.02	0.33	0.02	0.02									
287:	1	8	74															
	0.83	0.61	0.33															
289:	1	2	4	7	8	9	10	20	25	26	31	42	50	51	64	74	77	
	0.19	0.14	0.02	0.02	0.04	0.70	0.14	0.09	0.04	0.08	0.09	0.25	0.23	0.05	0.04	0.02	0.13	
291:	1	2	9	13	20	47	51											
	0.60	0.80	6.20	0.60	1.00	0.60	0.60											
295[4]:	2	9																
	1.00	1.00																
296:	1	2	7	8	9	20	23	25	26	40	42	44	51	53	64	67		
	0.37	0.37	0.05	0.05	1.05	0.11	0.16	0.26	0.37	0.05	0.11	0.05	0.05	0.05	0.32	0.05		

1. Refer to Table 1 for activity names.

2. Equipment with usage factors less than 0.01 are not included.

3. Refer to Table 3 for equipment names.

4. The results of there activities are based on relatively small sample size.

Table 11. Fuel Consumption Rates of Equipment Types for Different Activities

Activity Number[1]																	
201:	equipment code number[2]	1	2	4	7	8	9	10	12	13	14	20	26	44	47	48	74
	gallons/production unit	3.66	2.69	3.27	2.53	4.22	4.78	3.71	0.19	-	-	0.06	1.66	2.17	1.14	-	7.14
	operational rate of fuel consumption	7.35	6.67	5.10	4.33	11.88	3.17	3.08	0.38	-	-	0.78	1.21	1.86	0.66	-	1.68
		mpg[3]	mpg	mpg	mpg	mpg	mpg	mpg	gph[4]	hrs[5]	hrs	gph	gph	gph	gph	hrs	mpg
202:		1	2	8	9	10	12	13	14	20	23	26	42	44	47	48	50
		1.47	0.97	0.45	2.70	1.10	0.20	-	-	0.12	0.50	0.60	3.5	0.32	N.A.	-	-
		9.23	5.78	6.72	3.38	10.16	0.45	-	-	0.58	1.12	0.94	6.5	1.00	N.A.	-	-
		mpg	mpg	mpg	mpg	mpg	gph	hrs	hrs	gph	gph	gph	gph	gph	gph	hrs	mls
203:		1	2	7	9	10	13	14	16	20	25	26	42	47	50	51	
		0.17	0.55	2.00	1.63	1.00	-	-	-	0.12	0.81	0.29	N.A.	N.A.	-	-	
		10.29	9.22	6.28	3.63	3.02	-	-	-	1.17	5.00	1.50	N.A.	N.A.	-	-	
		mpg	mpg	mpg	mpg	mpg	hrs	hrs	hrs	gph	gph	gph	gph	gph	mls[6]	mls	
204[7]:		1	2	7	9	13	26										
		0.10	0.22	0.52	0.73	-	0.33										
		9.00	4.40	2.10	4.14	-	2.33										
		mpg	mpg	mpg	mpg	hrs	gph										
206:		1	2	4	7	9	10	13	44	47							
		1.41	1.00	0.42	1.70	2.43	2.62	-	0.59	-							
		7.07	3.56	8.08	2.76	3.00	3.63	-	1.39	-							
		mpg	mpg	mpg	mpg	mpg	mpg	hrs	gph	gph							
207:		1	2	7	9	10	13	26	42	44	47						
		2.89	3.07	4.57	6.15	6.55	-	2.29	1.03	3.05	3.63						
		4.33	5.75	2.92	2.17	2.36	-	6.00	1.13	2.45	1.56						
		mpg	mpg	mpg	mpg	mpg	hrs	gph	gph	gph	gph						

Activity Number																
209:	equipment code number	1	2	9	10	14	47	50	51	52						
	gallons/production unit	0.09	0.08	0.28	0.11	-	N.A.	-	-	0.12						
	operational rate of	7.58	6.62	2.54	4.58	-	N.A.	-	-	2.73						
	fuel consumption	mpg	mpg	mpg	mpg	hrs	gph	mls	mls	gph						
210:		1	2	9	10	12	14	20	25	26	27	47	53			
		0.21	0.54	0.93	0.76	N.A.	-	0.77	0.42	0.04	0.63	N.A.	0.67			
		8.24	5.27	2.74	6.20	N.A.	-	0.83	3.00	2.80	3.33	N.A.	1.65			
		mpg	mpg	mpg	mpg	gph	hrs	gph	gph	gph	gph	gph	mpg			
211:		1	2	9	10	20	22	25	27	30	42	47	54	55	56	57
		0.57	0.60	1.37	0.91	N.A.	N.A.	0.96	0.70	0.75	0.41	N.A.	1.05	-	-	-
		7.10	6.30	2.70	3.11	N.A.	N.A.	2.52	3.50	0.07	1.07	N.A.	2.25	-	-	-
		mpg	mpg	mpg	mpg	gph	hrs	gph	gph	gph	gph	gph	gph	hrs	hrs	hrs
212:		1	2	9	22	26	42	50	58							
		4.32	4.11	10.25	-	6.60	5.03	25.00	-	3.94						
		7.31	8.05	2.95	-	2.42	2.67	4.40	-	2.57						
		mpg	mpg	mpg	hrs	gph	gph	mpg	mls	gph						
213:		2	9	10	26											
		3.80	13.67	13.50	6.00											
		6.84	3.77	5.11	1.50											
		mpg	mpg	mpg	gph											
214:		1	2	9	10	13	15	25	26	47	54					
		.77	0.56	0.70	1.69	-	0.32	0.21	1.05	0.05	0.38					
		6.05	8.15	3.56	3.25	-	3.60	0.74	1.60	0.28	1.00					
		mpg	mpg	mpg	mpg	hrs	mpg	gph	gph	gph	gph					
219:		1	2	9	10	13	37									
		0.15	0.25	0.50	0.34	-	0.06									
		7.10	3.00	2.98	2.58	-	0.37									
		mpg	mpg	mpg	mpg	hrs	gph									

Activity Number												
221:	equipment code number	1	2	9	10	26	34	42	59			
	gallons/production unit	0.36	0.48	1.60	0.80	N.A.	-	0.28	0.04			
	operational rate of	7.10	7.92	4.30	2.88	N.A.	-	1.27	0.22			
	fuel consumption	mpg	mpg	mpg	mpg	gph	hrs	gph	gph			
222:		1	2	4	6	9	23	26	31	36		
		0.23	0.21	0.30	0.31	0.48	1.19	0.41	0.16	0.03		
		8.09	7.97	7.27	3.35	4.43	9.50	1.86	1.01	0.28		
		mpg	mpg	mpg	mpg	mpg	gph	gph	gph	gph		
223:		1	2	40								
		0.69	0.59	0.24								
		5.85	9.09	1.00								
		mpg	mpg	gph								
224[7]:		1	40	60								
		0.16	0.06	-								
		11.80	1.00	-								
		mpg	gph	hrs								
225:		1	2	3	4	9	10	26	31	32	36	61
		2.93	3.76	10.57	2.33	8.68	N.A.	5.46	1.23	1.35	0.47	-
		7.36	9.32	3.69	3.29	3.79	N.A.	3.25	1.15	0.09	0.31	-
		mpg	mpg	mpg	mpg	mpg	mpg	gph	gph	gph	gph	mls
226:		1	2	4	9	32	62	63				
		1.38	0.25	1.40	4.50	0.97	2.20	1.70				
		4.46	10.67	5.21	3.59	1.03	5.64	10.12				
		mpg	mpg	mpg	mpg	gph	mpg	mpg				
227:		1	2	34	35	36	42	59				
		0.87	0.45	-	0.04	0.06	0.26	0.06				
		5.50	7.66	-	0.17	0.50	1.26	0.19				
		mpg	mpg	hrs	gph	gph	gph	gph				

Activity Number																		
228:	equipment code number	1	2	9	49	62												
	gallons/production unit	0.11	0.05	0.30	0.05	0.10												
	operational rate of	8.06	9.40	5.11	9.83	6.17												
	fuel consumption	mpg	mpg	mpg	mpg	mpg												
229:		1	2	9	25	26												
		0.43	0.13	0.72	N.A.	0.27												
		3.75	9.26	3.53	N.A.	2.63												
		mpg	mpg	mpg	gph	gph												
231:		1	2	9	10	23	24	25	47	64	77							
		0.01	0.02	0.05	0.03	0.02	0.07	0.02	N.A.	0.01	N.A.							
		6.68	6.82	2.84	2.26	1.50	6.13	1.67	N.A.	2.00	N.A.							
		mpg	mpg	mpg	mpg	gph	gph	gph	gph	gph	mpg							
232:		1	2	9	10													
		0.24	0.16	0.42	0.78													
		9.10	9.93	4.80	4.00													
		mpg	mpg	mpg	mpg													
233:		1	2	9	10	12	20	23	24	26	42	44	51	65	66	67	68	70
		4.98	4.09	15.02	15.00	0.72	N.A.	4.00	10.96	5.30	1.70	9.00	-	-	-	-	-	6.70
		9.27	9.64	3.39	2.73	0.31	N.A.	1.23	3.20	2.38	5.88	3.00	-	-	-	-	-	-
		mpg	mpg	mpg	mpg	mpg	gph	gph	gph	gph	gph	mpg	gph	mls	hrs	mls	hrs	hrs
234:		1	2	9	22	25	26	47	58									
		6.01	5.49	14.37	-	14.78	6.58	5.00	8.43									
		7.92	6.92	2.50	-	3.92	2.13	1.44	1.98									
		mpg	mpg	mpg	hrs	gph	gph	gph	gph									
235:		1	2	9	10	11	23	26	45	71	72							
		1.28	0.92	7.20	1.92	2.50	2.50	1.00	-	-	0.70							
		7.88	7.50	3.39	6.83	3.35	1.25	1.25	-	-	0.70							
		mpg	mpg	mpg	mpg	mpg	gph	gph	hrs	mls	gph							

Activity Number														
239:	equipment code number	1	2	8	9	12	23	25	26	42	44	51	64	70	73
	gallons/production unit	0.35	0.17	0.09	0.39	N.A.	0.12	0.39	0.11	N.A.	0.03	-	0.34	0.05	0.38
	operational rate of	7.97	9.10	5.89	3.66	N.A.	1.48	2.20	1.56	N.A.	1.00	-	9.50	0.67	7.50
	fuel consumption	mpg	mpg	mpg	mpg	gph	gph	gph	gph	gph	gph	mls	gph	gph	gph
241:		1	2	4	9	44									
		2.12	1.54	1.60	3.45	3.26									
		5.69	7.71	1.50	3.36	3.26									
		mpg	mpg	mpg	mpg	gph									
243:		1	2	8	9	23	44	45	74	75					
		0.27	0.09	0.25	0.31	0.04	0.09	0.01	0.04	0.01					
		10.07	10.02	8.50	4.43	1.00	1.78	0.25	10.72	0.33					
		mpg	mpg	mpg	mpg	gph	gph	gph	mpg	gph					
244:		1	2	5	9	40									
		1.71	1.15	0.23	0.72	0.30									
		8.35	7.89	0.23	4.38	0.33									
		mpg	mpg	gph	mgp	gph									
245:		1	2	9	10	37	44	45	47	48	65				
		0.12	0.16	0.21	0.16	0.04	0.04	0.02	0.08	-	-				
		7.89	8.34	2.28	4.11	1.00	1.03	0.38	0.43	-	-				
		mpg	mpg	mpg	mpg	gph	gph	gph	gph	hrs	hrs				
251:		1	2	8											
		1.04	0.69	1.03											
		10.69	9.03	7.62											
		mpg	mpg	mpg											
257:		1	2	8	44	51	76								
		0.28	0.23	0.42	0.40	-	-								
		9.76	17.00	8.77	15.80	-	-								
		mpg	mpg	mpg	gph	mls	hrs								

Activity Number													
258:	equipment code number	1	2	9									
	gallons/production unit	0.70	0.14	0.26									
	operational rate of	5.78	12.76	4.20									
	fuel consumption	mpg	mpg	mpg									
259:		1	8										
		0.50	1.23										
		13.50	9.03										
		mpg	mpg										
261:		1	2	8	9	10	21	26	27	36	44	53	74
		1.01	0.43	0.94	1.65	N.A.	0.25	0.17	-	0.17	0.03	0.58	2.75
		11.23	6.50	10.11	2.66	N.A.	1.00	1.00	-	1.00	1.00	4.86	7.73
		mpg	mpg	mpg	mpg	mpg	gph	gph	hrs	gph	gph	mpg	mpg
265:		4	9	10	23	26	42	53	77				
		0.25	1.21	1.10	N.A.	1.13	N.A.	N.A.	N.A.				
		7.83	4.77	3.40	N.A.	2.71	N.A.	N.A.	N.A.				
		mpg	mpg	mpg	gph	gph	gph	mpg	mpg				
266:		1	2	9	10	27							
		1.67	1.58	4.21	4.77	-							
		16.15	11.78	3.80	4.01	-							
		mpg	mpg	mpg	mpg	hrs							
269:		1	2	9	10	26	44	53	74				
		0.24	0.32	0.47	0.56	0.24	0.28	1.08	0.22				
		9.05	11.68	4.18	5.51	4.00	1.18	2.71	13.31				
		mpg	mpg	mpg	mpg	gph	gph	mpg	mpg				
272:		2	4	9	25								
		0.21	0.50	0.76	0.31								
		9.36	4.86	4.17	1.43								
		mpg	mpg	mpg	gph								

Activity Number												
274:	equipment code number	2	9	10	13							
	gallons/production unit	0.09	0.23	0.27	-							
	operational rate of	5.51	1.91	1.24	-							
	fuel consumption	mpg	mpg	mpg	hrs							
275:		1	2	9	53							
		1.50	1.25	4.09	1.55							
		7.61	7.86	4.92	2.80							
		mpg	mpg	mpg	mpg							
276:		1	2	9	10	53						
		0.79	0.82	1.23	0.75	1.63						
		12.24	10.42	4.19	4.00	1.500						
		mpg	mpg	mpg	mpg	mpg						
277:		1	2	4	9	21	22	23	26	42	44	50	77
		0.31	0.26	0.07	0.79	0.20	-	0.35	0.28	0.05	0.16	-	N.A.
		7.30	7.91	10.75	3.13	1.50	-	1.71	2.44	0.64	2.39	-	N.A.
		mpg	mpg	mpg	mpg	gph	hrs	gph	gph	gph	gph	mls	mpg
279:		1	2	9	26	28	31	47					
		0.31	0.30	1.10	1.25	-	0.91	0.07					
		8.39	7.04	3.00	2.00	-	1.62	0.43					
		mpg	mpg	mpg	gph	hrs	gph	gph					
284:		1	2	7	9	10	13	26	50	51			
		0.76	0.90	3.03	1.35	1.54	-	0.85	-	-			
		11.09	8.15	4.33	3.84	3.80	-	3.30	-	-			
		mpg	mpg	mpg	mpg	mpg	hrs	gph	mls	mls			
287:		1	8	74									
		0.58	0.71	0.35									
		11.98	6.83	8.35									
		mpg	mpg	mpg									

Activity Number																		
289:	equipment code number	1	2	4	7	8	9	10	20	25	26	31	42	50	51	64	74	77
	gallons/production unit	0.68	0.62	1.44	0.50	0.91	1.37	2.00	0.23	0.59	0.43	0.75	3.74	-	-	1.47	1.13	0.90
	operational rate of fuel consumption	11.53 mpg	8.69 mpg	7.51 mpg	6.50 mpg	7.41 mpg	4.68 mpg	3.52 mpg	9.00 gph	3.22 gph	3.14 gph	3.00 gph	3.62 mpg	- mls	- mls	2.86 mpg	9.17 mpg	14.39 mpg
291:		1	2	9	13	20	47	51										
		0.07	0.08	0.26	-	0.06	0.03	-										
		8.19 mpg	11.47 mpg	3.58 mpg	- hrs	1.15 gph	0.34 gph	- mls										
295[7]:		2	9															
		0.10	0.50															
		13.20 mpg	2.16 mpg															
296:		1	2	7	8	9	20	23	25	26	40	42	44	51	53	64	67	
		0.27	0.16	0.17	2.00	0.43	0.03	0.23	0.50	0.60	0.04	N.A.	0.17	-	0.03	0.89	2.25	
		10.45 mpg	7.45 mpg	3.26 mpg	4.88 mpg	3.35 mpg	0.33 gph	1.71 gph	4.87 gph	4.67 gph	0.75 gph	N.A. gph	3.00 gph	- mls	0.20 gph	6.81 gph	6.00 gph	

1. Refer to Table 1 for activity names.
2. Refer to Table 3 for equipment names.
3. Miles per gallon.
4. Gallons per hour
5. Hours
6. Miles
7. Rates developed for these activities are based on relatively few observations.
8. Not available

Table 12. Average Miles and Hours per Production Unit.

Activity Number[1]																
201:	Equipment Code Number[2]	1	2	4	7	8	9	10	12	13	14	20	26	44	47	48	74
	Miles/Production Unit	30.70	18.30	13.60	5.90	27.70	13.60	11.30	---	---	---	---	---	---	---	---	10.70
	Hours/Production Unit	---	---	---	---	---	---	---	0.70	2.00	1.70	0.90	1.10	1.00	1.30	1.50	---
202:		1	2	8	9	10	12	13	14	20	23	26	42	44	47	48	50
		11.7	5.70	3.10	7.90	11.00	---	---	---	---	---	---	---	---	---	---	4.54
		---	---	---	---	---	0.44	0.78	0.78	0.47	0.46	0.62	0.50	0.41	1.33	1.00	---
203:		1	2	7	9	10	13	14	16	20	25	26	42	47	50	51	
		1.71	5.25	12.42	4.53	3.02	---	---	---	---	---	---	---	---	7.50	3.05	
		---	---	---	---	---	0.22	1.38	0.34	0.16	0.16	0.19	N.A.[3]	1.25	---	---	
204:		1	2	7	9	13	26										
		0.94	1.00	1.08	2.29	---	---										
		---	---	---	---	0.13	0.14										
206:		1	2	4	7	9	10	13	44	47							
		9.47	3.55	3.30	4.52	7.00	8.88	---	---	---							
		---	---	---	---	---	---	1.07	0.42	1.20							
207:		1	2	7	9	10	13	26	42	44	47						
		13.78	16.92	12.74	13.15	14.52	---	---	---	---	---						
		---	---	---	---	---	1.92	0.41	0.92	1.31	2.21						

Activity Number																
209:	Equipment Code Number	1	2	9	10	14	47	50	51	52						
	Miles/Production Unit	0.67	0.58	0.54	0.49	---	---	0.43	1.10	---						
	Hours/Production Unit	---	---	---	---	0.07	0.04	---	---	0.05						
210:		1	2	9	10	12	14	20	25	26	27	47	53			
		1.84	3.50	2.76	2.86	---	---	---	---	---	---	---	1.10			
		---	---	---	---	0.50	0.92	0.92	0.14	.01	0.10	0.92	---			
211:		1	2	9	10	20	22	25	27	30	42	47	54	55	56	57
		4.00	3.73	3.55	2.73	---	---	---	---	---	---	---	---	---	---	---
		---	---	---	---	0.26	0.40	0.39	0.30	1.25	0.36	0.33	0.30	0.41	0.27	0.67
212:		1	2	9	22	25	26	42	50	58						
		32.9	41.10	30.75	---	---	---	110.00	10.00	---						
		---	---	---	1.86	2.73	3.21	---	---	1.71						
213:		2	9	10	26											
		24.63	52.84	69.00	---											
		---	---	---	4.00											
214:		1	2	9	10	13	15	25	26	47	54					
		5.72	4.52	2.30	7.24	---	1.30	---	---	---	---					
		---	---	---	---	0.27	---	0.26	0.75	0.34	0.38					

Activity Number											
219:	Equipment Code Number	1	2	9	10	13	37				
	Miles/Production Unit	1.12	0.75	1.49	0.98	---	---				
	Hours/Production Unit	---	---	---	---	0.14	0.17				
221:		1	2	9	10	26	34	42	59		
		2.37	3.66	5.57	2.30	---	---	---	---		
		---	---	---	---	.03	0.22	0.23	0.19		
222:		1	2	4	6	9	23	26	31	36	
		1.76	1.55	1.93	1.05	1.96	---	---	---	---	
		---	---	---	---	---	0.13	0.22	0.29	0.11	
223:		1	2	40							
		4.73	6.33	---							
		---	---	0.24							
224:		1	40	60							
		1.84	---	---							
		---	0.06	0.19							
225:		1	2	3	4	9	10	26	31	32	36	61
		23.67	33.11	44.5	7.67	27.52	7.6	---	---	---	---	58.5
		---	---	---	---	---	---	1.46	1.17	1.50	2.70	---

Activity Number																		
226:	Equipment Code Number	1	2	4	9	32	62	63										
	Miles/Production Unit	6.17	2.67	7.30	28.03	---	12.4	17.20										
	Hours/Production Unit	---	---	---	---	1.10	---	---										
227:		1	2	34	35	36	42	59										
		5.10	3.33	---	---	---	---	---										
		---	---	0.21	0.25	0.13	0.21	0.31										
228:		1	2	9	49	62												
		0.82	0.50	1.53	0.48	0.62												
		---	---	---	---	---												
229:		1	2	9	25	26												
		1.61	1.14	2.35	---	---												
		---	---	---	0.13	0.11												
231:		1	2	9	10	23	24	25	47	64	77							
		0.08	0.12	0.14	0.07	---	---	---	---	---	0.06							
		---	---	---	---	0.01	0.01	0.01	0.01	0.01	---							
232:		1	2	9	10													
		2.18	1.59	2.00	3.14													
		---	---	---	---													
233:		1	2	9	10	12	20	23	24	26	42	44	51	65	66	67	68	70
		39.82	35.67	46.82	41.00	---	---	---	---	---	10.00	---	27.50	---	31.00	---	---	---
		---	---	---	---	1.86	2.00	3.70	3.21	2.67	---	3.00	---	3.00	---	3.50	2.00	5.0

Activity Number															
234:	Equipment Code Number	1	2	9	22	25	26	47	58						
	Miles/Production Unit	47.81	36.89	35.36	---	---	---	---	---						
	Hours/Production Unit	---	---	---	3.00	3.47	3.15	4.38	3.00						
235:		1	2	9	10	11	23	26	45	71	72				
		19.02	6.81	24.88	13.10	6.91	---	---	---	0.50	---				
		---	---	---	---	---	2.00	0.80	2.00	---	1.00				
239:		1	2	8	9	12	23	25	26	42	44	51	64	70	73
		2.57	1.88	0.54	1.39	---	---	---	---	---	---	1.92	---	---	---
		---	---	---	---	0.22	0.09	0.18	0.06	0.11	0.03	---	0.04	0.08	0.05
241:		1	2	4	9	44									
		10.97	9.90	1.47	10.73	---									
		---	---	---	---	0.89									
243:		1	2	8	9	23	44	45	74	75					
		1.77	0.87	2.13	1.38	---	---	---	0.28	---					
		---	---	---	---	0.04	0.05	0.03	---	0.05					
244:		1	2	5	9	40									
		14.50	9.11	0.97	3.06	---									
		---	---	---	---	0.89									
245:		1	2	9	10	37	44	45	47	48	65				
		0.95	1.37	0.42	0.65	---	---	---	---	---	---				
		---	---	---	---	0.04	0.03	0.05	0.13	0.04	0.04				

Activity Number													
251:	Equipment Code Number	1	2	8									
	Miles/Production Unit	8.00	6.03	7.60									
	Hours/Production Unit	---	---	---									
257:		1	2	8	44	51	76						
		2.90	3.83	3.72	---	2.94	---						
		---	---	---	0.04	---	0.11						
258:		1	2	9									
		2.81	1.75	1.08									
		---	---	---									
259:		1	8										
		6.75	10.66										
		---	---										
261:		1	2	8	9	10	21	26	27	36	44	53	74
		8.08	5.40	8.99	3.72	2.57	---	---	---	---	---	2.83	21.25
		---	---	---	---	---	0.25	0.17	0.33	0.16	0.03	---	---
265:		4	9	10	23	26	42	53	77				
		1.96	4.08	3.93	---	---	---	0.88	0.88				
		---	---	---	0.13	0.50	0.25	---	---				
266:		1	2	9	10	27							
		24.96	18.07	15.81	17.79	---							
		---	---	---	---	0.50							

Activity Number													
269:	Equipment Code Number	1	2	9	10	26	44	53	74				
	Miles/Production Unit	1.96	3.10	1.71	1.39	---	---	2.92	2.81				
	Hours/Production Unit	---	---	---	---	0.06	0.24	---	---				
272:		2	4	9	25								
		1.94	2.43	2.77	---								
		---	---	---	0.22								
274:		2	9	10	13								
		0.53	0.47	0.34	---								
		---	---	---	0.11								
275:		1	2	9	53								
		10.98	9.30	15.59	4.33								
		---	---	---	---								
276:		1	2	9	10	53							
		8.11	8.01	5.06	3.00	2.43							
		---	---	---	---	---							
277:		1	2	4	9	21	22	23	26	42	44	50	77
		1.82	1.67	0.82	2.27	---	---	---	---	---	---	0.73	0.58
		---	---	---	---	0.14	0.31	0.21	0.12	0.08	0.09	---	---
279:		1	2	9	26	28	31	47					
		3.32	1.51	2.96	---	---	---	---					
		---	---	---	0.63	0.75	0.58	0.15					

Activity Number																	
284:	Equipment Code Number	1	2	7	9	10	13	26	50	51							
	Miles/Production Unit	6.97	7.33	13.25	4.35	4.92	---	---	2.25	2.25							
	Hours/Production Unit	---	---	---	---	---	0.25	0.19	---	---							
287:		1	8	74													
		3.47	4.53	2.95													
		---	---	---													
289:		1	2	4	7	8	9	10	20	25	26	31	42	50	51	64	74	77
		7.44	4.86	10.68	4.88	6.31	5.08	4.84	---	---	---	---	11.96	11.43	5.14	3.69	10.31	12.03
		---	---	---	---	---	---	---	0.03	0.18	0.13	0.25	---	---	---	---	---	---
291:		1	2	9	13	20	47	51										
		0.59	0.87	0.96	---	---	---	0.46										
		---	---	---	0.06	0.06	0.08	---										
295:		2	9															
		1.38	1.08															
		---	---															
296:		1	2	7	8	9	20	23	25	26	40	42	44	51	53	64	67	
		2.77	0.97	0.55	9.75	1.41	---	---	---	---	---	---	---	9.75	---	---	---	
		---	---	---	---	---	0.05	0.13	0.10	0.09	0.05	0.19	0.06	---	0.13	0.15	0.38	

1. Refer to Table 1 for activity names.
2. Refer to Table 3 for equipment types.
3. Not available.

Table 13. Tests to Compare Operational Rates of Fuel Consumption in Interstate and Other State Highway Systems.

Test Number	Season	Activity Number[1]	Subdistrict Number[2]	Equipment Number[3]	Rate	Consumption Rate		Test Significance[6]
						Interstate	Other State Highway	
1	Fall	207	2	1	mpg[4]	3.02	4.49	Yes
2	Fall	207	2	2	mpg	3.59	4.83	Yes
3	Fall	207	2	9	mpg	0.84	1.86	Yes
4	Fall	207	2	44	gph[5]	1.80	1.50	Yes
5	Fall	251	1	8	mpg	7.89	8.80	Yes
6	Fall	276	1	9	mpg	3.49	4.37	Yes
7	Fall	276	2	1	mpg	8.29	7.69	No
8	Fall	276	5	1	mpg	9.50	10.41	Yes
9	Fall	276	5	9	mpg	4.13	5.12	Yes
10	Fall	277	5	1	mpg	11.02	12.22	Yes
11	Fall	277	5	2	mpg	6.33	6.48	No
12	Winter	207	2	2	mpg	3.70	5.58	Yes
13	Winter	207	2	9	mpg	2.30	2.81	Yes
14	Spring	201	1	2	mpg	4.03	5.46	Yes
15	Spring	201	5	9	mpg	2.07	2.91	Yes
16	Spring	222	5	36	gph	0.46	0.50	No
17	Spring	241	5	1	mpg	6.74	5.70	Yes
18	Spring	275	5	9	mpg	2.60	3.65	Yes
19	Spring	277	5	44	gph	2.17	2.88	Yes
20	Spring	279	5	9	mpg	3.05	4.85	Yes

1 Refer to Table 1 for activity names

2 Refer to Figure 5 for subdistrict names and locations

3 Refer to Table 3 for equipment types.

4 Miles per gallon

5 Gallons per hour

6 Yes: The averages are significantly different(at 90% to 95% levels of confidence)

No: The averages are not significantly different (at 90% to 95% levels of confidence)

Table 14. Comparative Tests for Seasonal Variations

Test No.	Activity No.[1]	Subdistrict No.[2]	Equipment No.[3]	Consumption Rate	Average Fuel Consumption				Test Significance[6]
					Fall	Winter	Spring	Summer	
1	201	2	2	mpg[4]	8.26	7.29			Yes
2	201	2	9	mpg	3.01	2.97			No
3	201	4	2	mpg	8.78	6.23			Yes
4	201	4	9	mpg	3.98	2.84			Yes
5	201	6	2	mpg	8.65	5.89			Yes
6	201	6	9	mpg	3.40	2.57			Yes
7	201	6	47	gph[5]	1.08	0.35			Yes
8	207	2	1	mpg	4.24	2.00			Yes
9	207	2	2	mpg	5.34	4.68			No
10	207	2	9	mpg	2.73	1.67			Yes
11	210	2	1	mpg	8.02	8.31			No
12	211	2	10	mpg	2.40	2.37			No
13	225	2	2	mpg	8.93	7.00			Yes
14	225	2	9	mpg	3.57	3.33			No
15	232	2	1	mpg	7.59	6.94			Yes
16	235	6	1	mpg	11.31	7.94			Yes
17	239	2	1	mpg	8.83	4.44			Yes
18	251	2	8	mpg	8.24	8.38			No
19	251	4	8	mpg	6.44	6.44			No
20	251	6	8	mpg	8.92	8.00			Yes
21	261	4	1	mpg	8.90	4.91			Yes
22	261	4	9	mpg	4.29	2.42			Yes
23	261	6	1	mpg	13.67	12.05			Yes
24	265	2	26	pgh	1.25	2.04			Yes
25	265	4	26	gph	1.58	4.30			Yes
26	276	2	1	mpg	9.38	7.78			Yes
27	276	2	9	mpg	5.91	4.31			Yes
28	276	4	1	mpg	12.09	11.13			No
29	276	4	2	mpg	9.56	6.47			Yes
30	276	6	1	mpg	15.27	12.94			Yes
31	276	6	2	mpg	15.10	13.41			Yes
32	276	2	1	mpg	7.78	9.38			No
33	276	2	9	mpg	5.91	4.31			Yes
34	284	6	1	mpg	11.60	12.40			No
35	284	6	26	gph	1.42	1.30			Yes

Test No.	Activity No.	Subdistrict No.	Equipment No.	Consumption Rate	Average Fuel Consumption				Test Significance
					Fall	Winter	Spring	Summer	
36	289	2	1	mpg [4]	11.67	9.60			Yes
37	289	2	9	mpg	5.20	4.81			No
38	289	2	25	gph	1.67	3.00			Yes
39	289	4	9	mpg	5.00	3.35			Yes
40	289	4	10	mpg	3.76	3.33			Yes
41	289	6	8	mpg	6.62	3.00			Yes
42	289	6	9	mpg	5.36	4.67			Yes
43	201	1	2	mpg	8.18		5.54		Yes
44	201	1	9	mpg	4.01		2.84		Yes
45	201	1	10	mpg	3.93		3.14		Yes
46	201	1	12	gph	0.40		0.40		No
47	201	2	2	mpg	7.50		7.29		No
48	201	2	9	mpg	2.97		2.62		Yes
49	201	2	10	mpg	3.35		2.62		Yes
50	201	4	1	mpg	10.38		9.91		No
51	201	4	2	mpg	8.78		6.27		Yes
52	201	4	4	mpg	7.46		5.27		Yes
53	201	4	9	mpg	3.98		2.95		Yes
54	201	5	2	mpg	8.75		7.98		Yes
55	201	5	9	mpg	4.18		4.74		No
56	201	6	2	mpg	8.65		7.96		Yes
57	201	6	9	mpg	3.40		3.30		No
58	201	6	10	mpg	2.85		2.78		No
59	207	4	2	mpg	8.54		5.44		Yes
60	207	4	7	mpg	3.56		2.43		Yes
61	207	4	9	mpg	2.76		2.65		No
62	207	4	44	gph	2.62		3.19		Yes
63	211	5	1	mpg	7.49		7.39		No
64	211	5	25	gph	1.90		1.99		Yes
65	222	5	2	mpg	9.71		8.06		Yes
66	222	5	9	mpg	4.74		3.37		Yes
67	222	5	36	gph	0.24		0.46		Yes
68	231	5	1	mpg	7.77		7.70		No
69	231	5	9	mpg	2.42		1.77		Yes
70	233	5	2	mpg	9.17		7.96		Yes
71	233	5	9	mpg	3.66		3.21		No

Test No.	Activity No.	Subdistrict No.	Equipment No.	Consumption Rate	Average Fuel Consumption				Test Significance
					Fall	Winter	Spring	Summer	
72	233	5	23	gph	1.50		1.70		Yes
73	251	4	8	mpg	6.44		5.37		Yes
74	251	5	8	mpg	8.84		8.10		Yes
75	261	5	9	mpg	3.28		2.39		Yes
76	269	5	2	mpg	13.16		9.42		Yes
77	269	5	9	mpg	4.60		3.60		Yes
78	269	5	53	mpg	3.33		2.40		Yes
79	272	5	2	mpg	11.45		8.31		Yes
80	272	5	9	mpg	5.31		3.61		Yes
81	275	5	9	mpg	3.91		2.24		Yes
82	276	4	2	mpg	9.60		9.00		Yes
83	276	4	9	mpg	5.00		4.70		No
84	276	5	1	mpg	10.05		9.40		Yes
85	276	5	9	mpg	4.79		3.77		Yes
86	277	4	2	mpg	6.43		5.41		Yes
87	277	4	9	mpg	2.61		1.53		Yes
88	277	4	26	gph	1.67		3.00		Yes
89	277	5	1	mpg	11.54		7.08		Yes
90	277	5	2	mpg	11.85		6.40		Yes
91	284	4	7	mpg	4.21		3.15		Yes
92	284	4	9	mpg	3.63		3.53		No
93	289	4	9	mpg	5.00		4.30		No
94	289	4	10	mpg	3.76		1.19		Yes
95	289	4	74	mpg	10.22		8.11		Yes
96	289	5	42	mpg	3.44		3.66		No
97	201	1	2	mpg	8.18			6.65	Yes
98	201	1	9	mpg	4.01			3.85	No
99	201	1	10	mpg	3.93			3.48	No
100	201	1	12	gph	0.40			0.33	No
101	201	2	2	mpg	7.29			9.07	Yes
102	201	2	9	mpg	2.97			2.93	No
103	201	4	2	mpg	8.78			6.81	Yes
104	201	4	9	mpg	3.98			3.99	No
105	202	1	2	mpg	4.43			2.63	Yes
106	206	1	9	mpg	7.35			3.56	Yes
107	206	4	9	mpg	3.54			2.76	No
108	206	4	44	gph	0.90			1.57	Yes
109	210	1	2	mpg	4.50			7.16	No

Test No.	Activity No.	Subdistrict No.	Equipment No.	Consumption Rate	Average Fuel Consumption				Test Significance
					Fall	Winter	Spring	Summer	
110	210	1	9	mpg	2.06			3.75	No
111	210	1	10	mpg	2.99			3.48	No
112	221	1	2	mpg	9.27			7.14	Yes
113	221	1	42	gph	1.28			1.21	No
114	221	1	59	gph	0.20			0.27	No
115	221	6	2	mpg	11.24			9.16	Yes
116	221	6	42	gph	1.15			1.22	No
117	222	4	2	mpg	8.87			7.34	No
118	222	4	36	gph	.13			0.29	Yes
119	227	4	1	mpg	7.80			2.03	Yes
120	251	4	8	mpg	6.44			6.63	No
121	257	4	8	mpg	9.56			7.45	No
122	276	4	1	mpg	12.09			16.66	Yes
123	277	4	2	mpg	6.43			3.90	Yes
124	277	4	9	mpg	2.61			1.49	Yes
125	284	4	9	mpg	3.63			3.89	No
126	289	4	2	mpg	9.36			12.00	Yes
127	289	4	9	mpg	5.00			5.00	No
128	289	4	10	mpg	3.76			3.66	No
129	289	4	77	mpg	14.2			15.61	No
130	231	4	1	mpg			2.75	7.67	Yes
131	231	4	2	mpg			3.81	7.22	Yes
132	231	4	9	mpg			2.25	3.61	Yes
133	231	4	24	gph			6.40	8.94	Yes
134	239	4	9	mpg			3.44	2.83	Yes
135	251	4	8	mpg			5.37	6.00	Yes
136	277	4	2	mpg			5.41	3.90	Yes
137	277	4	9	mpg			1.53	1.49	No
138	284	4	9	mpg			3.53	3.89	No

1 Refer to Table 1 for activity names

2 Refer to Figure 5 for subdistrict names and locations

3 Refer to Table 3 for equipment types

4 Miles per gallon

5 Gallons per hour

6 Yes: Test is significant at 90% or 95% confidence level.
No: Test is not significant at 90% or 95% confidence level.

Table 15: Equipment Types with Dominant Fuel Use

Activity No.[1]	List of Dominant Equipment Types	% of Total Fuel consumed	Total (%)
263	Snow Truck	98	98
201	Dump Truck Pickup crew Cab	49 33	82
289	Dump Truck Tractor Truck Do-all Truck	35 31 14	80
221	Tractor Truck Pickup crew Cab Dump Truck	42 21 7	70
207	Dump Truck Pickup Crew Cab Do-all Truck Utility Truck	47 15 15 7	84
284	Dump Truck Utility Truck Loader	46 36 8	90
210	Do-all Truck Dump Truck Pickup Crew Cab Pickup Truck	47 22 9 7	85
212	Dump Truck Pickup Truck Loader Pickup Crew Cab Broom Tractor	65 7 5 5 3	85
251	Utility Truck Pickup Truck	78 18	96

1 Refer to Table 1 for activity names.

Table 16. Average Fuel Consumption Rates for Snow and Ice Removal Activity

Equipment	Fuel Consumption Rates in Gallons per Man-Hour			
	Subdistrict Number*			
	4	5	6	Average
Truck				
Route Class I	5.76	5.16	4.92	5.27
Route Class II	5.03	4.78	4.42	4.73
Route Class III	4.83	4.54	4.21	4.60
Loader	1.36	1.70	0.96	1.17

*Refer to Figure 5 for subdistrict names and locations.

Table 17: Fuel Consumption Estimation for Activities Not Included in the Sample.

Activity No.[1]	Estimation Procedure
205	Consumption rate of activity 204 was used. To convert the production unit of foot-mile(activity 204) to lane-mile(activity 205), an averge lane width of 11 feet was assumed.
249	Same as activity 243.
271	Same as activity 272.
273	Same as activity 273.
281	No fuel is needed.
283	Same as activity 296.

1 Refer To Table 1 for Activity Names.

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